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VMetric Spare Parts Optimization Model Validation

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16. Abstract

This report describes a study conducted by the U.S. Coast Guard Research and Development Center to determine if Vmetric, a spare parts optimization model, can improve the performance of the Coast Guard aviation logistics system.

Aircraft spare part stocking levels at the Coast Guard's Aviation Repair and Supply Center (ARSC) are determined using outdated inventory models that overestimate required stock levels. To reduce inventory levels, ARSC obtained VMetric, which determines stocking levels for spare parts to minimize the cost of inventory while meeting aircraft availability constraints. It can also be used to maximize availability given a cost constraint. The objectives of this project are to validate that the conditions and assumptions under which VMetric provides an optimal solution are met, and to provide a level of assurance that any changes in stocking levels recommended will not result in a reduction in aircraft availability.

A simulation model of the logistics system was developed by the Coast Guard Research and Development Center to test the recommended stocking levels without actually testing them in the field. The simulation was validated using historical data and used to compare the performance resulting from using VMetric stock levels to that achieved using historical stock levels.

Examination of the VMetric assumptions showed the theory behind the model closely follows that of the Coast Guard aviation spare parts logistics system and provides significant performance improvements. VMetric stock levels provided the same aircraft availability as historical levels with a 34% to 54% reduction in stock position. VMetric improved availability when funding levels for spares remained unchanged. Field tests performed at Air Stations Cape Cod and Astoria support these conclusions.

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METRIC CONVERSION FACTORS

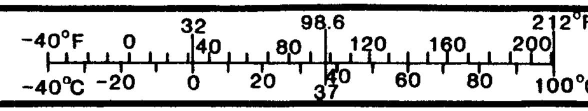
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS

ACMS	Aviation Computerized Maintenance System
AIRSTA	U. S. Coast Guard Air Station
AMMIS	Aviation Maintenance Management Information System
ARENA	Systems Modeling Corporation Discrete Event Simulation Modeling Package
ARSC	Aviation Repair and Supply Center
EOQ	Economic Order Quantity
ERQ	Economic Repair Quantity
HH-60J	Sikorsky HH-60J Helicopter
HSK	Helicopter Support Kit
IPL	Indentured Parts List (Parts Indenture Structure)
LRS	Lateral Supply or Parts Pooling
R&DC	U. S. Coast Guard Research and Development Center
VMetric	Vari-Metric Spare Parts Optimization Model

EXECUTIVE SUMMARY

The Coast Guard operates the 7th largest air force in the world. Its fleet of 190 rotary and fixed wing aircraft are divided between four different airframes. This fleet requires a spare parts inventory valued at approximately $600 million to support operational requirements. To most efficiently manage these inventories, models are needed that determine which spare parts to stock and where to store them in order to meet operational requirements at minimum cost. The Aviation Repair and Supply Center (ARSC) purchased VMetric, an inventory management model, for this purpose. Prior to changing historical stocking levels, an independent validation of the model was required to ensure that mission performance would remain constant or improve. This study tested the assumptions made by VMetric, used simulation to see how recommended stocking levels would affect operational readiness, and performed field tests to further substantiate the recommendations. This report provides strong evidence that VMetric is valid for the Coast Guard aviation logistics system and has significant potential to reduce spare parts inventory costs.

Objectives

The objective of this project was to provide a full, impartial validation of the VMetric model for ARSC implementation. The validation process was to determine the following:

- If the assumptions made by the model were valid for the Coast Guard aviation spare parts logistics system.
- If changes in the stock levels recommended by the model would result in an unacceptable reduction in operational availability, and
- If the cost savings provided by stocking spare parts in accordance with the model would justify the cost and effort to implement the model.

Approach

The work performed included testing the VMetric model assumptions using historical data, determining the model's value by comparing its performance to that of historical models, and performing field tests to validate and evaluate the recommended stock levels directly in the field.

A key component in implementing VMetric is an accurate representation of an aircraft as a hierarchy of parts, also known as a parts indenture structure. ARSC created the indenture structure for the HH-60J aircraft. This effort was costly, time consuming and was the biggest obstacle in running the VMetric model on schedule. Tests were made using a subset of eight critical parts taken from the HH-60J indenture structure.

In order to test the performance of the VMetric recommended stock levels, a simulation model was developed to mimic the real-world aircraft logistics system. The simulation model was validated using Fiscal Year 1996 backorder and failure data from the Aviation Maintenance Management Information System (AMMIS) data base. The simulation was run with VMetric allocating funds comparable to two historical spare parts stocking policies: a high-end policy based on the current spare parts allowance list and a low-end policy based on a sample of what was actually on hand at the air stations and ARSC. Simulations were performed for both of these policies to determine if the VMetric stocking policy provides better results than historical policies.

Field tests were conducted at Air Station Cape Cod and Air Station Astoria to further test if VMetric provided an improvement over the current system. Results of the simulations and field tests were then extrapolated to include all parts, all airframes, and all air stations.

Findings

This study proved that the theory behind the VMetric model closely follows the practices of the Coast Guard aviation spare parts logistics system. Seven of the ten parts chosen for the study proved to follow the assumed failure distribution and the remaining parts did not have an adverse effect on the output of the model.

Test runs of the VMetric model were done with a subset of eight parts taken from the indenture structure. The recommended stocking levels passed reviews for correctness and plausibility by the inventory managers at ARSC.

Simulation of historical stocking policies showed that VMetric could improve aircraft availability and decrease required spare parts. For the low-end policy, availability remained constant with a 34% decrease in stock position compared to the historical policy. With stock position held constant at $3.0 million, VMetric increased availability from 91.2% to 95.8%. For the high-end policy, availability remained constant with a 54% decrease in stock position compared to the historical policy. All backorders could be eliminated with a spare parts stock position 16% less than the historical policy. In addition, the VMetric stocking recommendations were found to be less sensitive to small changes in conditions than the historical policy.

In the field tests, based on 3 1/2 months of data collected on the subset of eight parts, the low-end VMetric policy provided improved availability at Air Station Cape Cod and maintained availability at Air Station Astoria. The high-end VMetric policy improved availability to 100% by eliminating all base level backorders at both air stations.

Estimates show that VMetric could potentially reduce stock position 34% to 54% while still maintaining current availability levels. A substantial one time reduction in stock position could result by identifying excess parts in the current inventory and liquidating them. However, the many factors involving inventory salvage value were not investigated in this study and an accurate estimate is not possible. This

study has shown that the VMetric model is applicable to the spare parts inventory system for the HH-60J aircraft. It has the potential to significantly reduce spare parts inventory stock position while availability is unaffected or even improved.

Recommendations

Specific recommendations are provided below and are detailed in Section 7.0 of this report:

- The VMetric model should be completely implemented for the HH-60J aircraft and tested in the field.
- Once proven for the HH-60J, VMetric should be implemented for the HH-65A, HU-25, and HC-130.
- A process should be developed and implemented for periodically updating and validating VMetric model inputs and running the model to update stock level recommendations.
- Further research should be conducted to determine if VMetric can be applied to other Coast Guard logistics systems, in particular the cutter fleet.
- VMetric and the simulation model developed to validate it should be used by inventory managers as what-if analysis tools to improve inventory management.
- VMetric should be used to develop an optimal stocking policy for Helicopter Support Kits.

1.0 INTRODUCTION AND PURPOSE

The Coast Guard Research and Development Center received a request for R&D Center support from the Office of Engineering, Logistics and Development (G-E), number ARSC-02-95 dated 03 October 1995. This document requested support for the validation of the proposed VMetric inventory model being placed in service at the Coast Guard Aircraft Repair and Supply Center (ARSC). The inventory model is to set stocking policy based on operational needs, and provide a quantitative connection between operations, maintenance and supply functions within Coast Guard Aviation.

The VMetric inventory model quantifies the relationship between the cost of maintaining a spare parts inventory and the improvement in operational availability that such an inventory allows. In addition, the model provides a measure of the expected reduction in availability that corresponds to a reduction in spare part stock levels. This information provides decision makers with a meaningful criterion for how best to allocate the funds available for logistics support.

A change in spares management policy has a direct and immediate impact on the availability of Coast Guard aircraft, which in turn affects mission performance. Before reducing spare parts stocking levels, some assurance is required that aircraft availability, and therefore mission performance, will remain at an acceptable level. While the VMetric model has been applied with great success in a number of applications with strong similarities to the Coast Guard's logistics system, it is reasonable and prudent to validate the model in the Coast Guard environment prior to full scale implementation of its recommended spare part stocking levels.

This report discusses relevant background information for understanding the technical approach, details of the research methods, analysis of data in terms of the principal objectives of the work, and the implications of the results.

2.0 OBJECTIVES

The objective of this project is to provide a full, impartial validation of the VMetric spare parts optimization model, as implemented by ARSC. This validation provides a level of assurance that the model is appropriate for Coast Guard use, that it has been implemented correctly, and that any changes in stocking levels recommended by the model will not result in an unacceptable reduction in operational availability.

It is important that the ultimate decision makers are satisfied that the model is both applicable and beneficial to Coast Guard aviation spare parts management. If the proposed tests are performed with satisfactory results, then the program manager can be satisfied that the risk of an improper or inappropriate implementation of this model is minimal.

The work performed included testing the VMetric model assumptions using historical data, testing the VMetric model's validity using simulation to test the performance of its recommended stocking levels, and performing field tests at air stations to further test the recommended stock levels directly in the field.

The validation process focused on three specific questions:

- Is the VMetric model being implemented at ARSC in accordance with the guidelines provided by its developer? Are the underlying assumptions of the VMetric model appropriate for Coast Guard implementation?
- Is the availability of Coast Guard aircraft kept at an acceptable level after implementing the stocking levels recommended by VMetric?
- Does VMetric improve system performance?

3.0 BACKGROUND

In the Coast Guard aviation logistics system, spare part stocking levels are determined using Economic Order Quantity (EOQ) and Economic Repair Quantity (ERQ) models. This approach currently ensures that the Coast Guard meets or exceeds the availability requirements for aircraft, but the models have several shortcomings, including:

(1) The EOQ model overestimates required on-hand inventories, and stock levels have been increasing steadily. In fact, recent examination of the computer code in AMMIS that implements the EOQ model has shown that errors exist in the implementation, possibly resulting in invalid reorder point decisions.

(2) No differentiation is made between depot and base location of spares. This ignores the reality that a part held at a base is critically different from the same part held at the depot with respect to availability.

(3) Demand is treated as a known, fixed rate, rather than an unknown, random process.

(4) The relationship between availability and inventory level is not modeled, making it impossible to link operations, maintenance and supply functions. This is a functionality requested of the Coast Guard R&D Center in Request for R&D Support ARSC-01-95 which seeks assistance in developing an operations, maintenance, and supply decision support system that would assist the aviation community in validating availability requirements and to analyze the effect of operational policies on logistical support and maintenance costs.

3.1 The VMetric Model

To address the above shortcomings, ARSC obtained a spare parts optimization model called VMetric. This is commercial off-the shelf software developed and marketed by Systems Exchange, Inc., of Pacific Grove, CA. VMetric is a multi-echelon, multi-indenture inventory stock optimizing model. Multi-echelon means that it models inventories held concurrently at operating units, such as air stations, and at support depots, such as ARSC. Multi-indenture means that the model incorporates the concept of the aircraft's engineering parts hierarchy. First indenture parts are called line-replaceable units (LRU's), items that can be removed from the aircraft on the flight line. These items can be disassembled in a repair shop and second indenture parts (SRU's) replaced. These assemblies may be further broken down to sub-assemblies and components, and some of these may ultimately be used in different LRU's. VMetric takes the different locations that parts may be stored and the engineering parts hierarchy into account when determining an optimal stocking policy.

The VMetric model uses marginal analysis to allocate available funds to purchase spares that provide the largest decrease in the expected number of backorders for items which are essential to the availability of an aircraft. The model can account for policies such as lateral supply (shipping parts from base to base

also known as "parts pooling"), cannibalization (consolidating shortages so that they affect the minimum number of aircraft), redundant systems, and differing criticality (a measure of the importance of the part).

VMetric uses a systems approach instead of an item approach to optimize stock levels. In the traditional item approach, stocking decisions for each part are made separately from all other parts. The main disadvantage of this is that system availability and total investment in the system spares is not controllable. With the systems approach, stock levels can be optimized to meet specific system-wide availability or cost targets.

Like any model, VMetric incorporates certain simplifying assumptions and conditions which make the calculation of the optimal stocking policy tractable. The primary need addressed by this project is to validate that the conditions under which VMetric provides an optimal solution are met, and that the assumptions it operates under are valid, or, if not, that the differences between the model and the actual Coast Guard implementation are not significant. In addition, it is necessary to test the model to ensure its recommendations will improve Coast Guard stocking policies for aviation spare parts.

3.2 The Current Inventory System

The purpose of the Coast Guard Aviation Inventory system is to ensure that aircraft have the parts necessary to remain operational to meet mission requirements. This is accomplished by maintaining spare parts at air stations and at the central repair facility in Elizabeth City, NC (ARSC). Limitations on funding require inventory managers to minimize spare parts inventories while meeting operational requirements.

In VMetric terminology the Coast Guard logistics system is considered a two echelon system because inventories for aircraft are held at the air station level (first echelon), and at ARSC (second echelon). The system is multi-indenture because each aircraft is comprised of a set of parts that may be removed and replaced at the air station to effect repair (LRUs), and those LRUs may be taken apart into sub-assemblies considered second indenture parts or SRUs. Furthermore, the SRUs can be further disassembled into their component or lower indenture parts.

While certain repairs can be done at the air stations, most parts are sent to ARSC for repair or replacement. When a part fails that is critical to the aircraft's operation, the aircraft is not "available" (down) and its availability is degraded until the part is repaired or replaced. Therefore an aircraft's availability is equal to 100% minus the percentage of time it spends in a maintenance status awaiting parts and repairs[1]. This down time consists of the time it takes to remove and diagnose a failed part, the shipping time between the air stations and ARSC, the time to repair or procure the failed part, and the time to install and test the part on the aircraft.

[1] Scheduled maintenance also affects an aircraft's availability however since the maintenance is scheduled, demand for required parts is less variable and can be planned for in advance without the use of VMetric.

3.3 Terminology

The following terms are used throughout this report. Some are terms associated with VMetric theory and others are Coast Guard inventory system terms.

- Availability - The percentage of time an aircraft is available for operations. In this study, availability is analogous to the supply component of availability plus an unplanned maintenance component. It does not include the downtime caused by planned maintenance.
- Availability Degraders -Parts that had the highest number of Priority 2 backorders, those which cause an aircraft to be down.
- Backorder - When a part is not on hand when demanded at either a base or the depot. A base level backorder means that an aircraft is not available.
- Base and Air Station - Used synonymously to refer to a U.S. Coast Guard Air Station where aircraft are based for operational purposes.
- Cannibalization - The practice of consolidating backorders at an air station by taking parts from one aircraft and putting them on another.
- Child - An assembly or part that is part of another assembly (parent).
- Depot and ARSC - Used synonymously to refer to the Coast Guard Repair and Supply Center in Elizabeth City, NC. where aircraft spare parts are stored and repaired.
- Lateral Supply - The practice of sending parts from one air station to another to fill backorders. Commonly called parts pooling in the Coast Guard.
- Line replaceable unit (LRU) - A part or assembly of parts that can be removed from an aircraft on the flightline.
- Logistics Cost Drivers - Parts which contribute the most to the overall cost of an aircraft's inventory.
- NIIN - National Item Identification Number. A unique number assigned to a part.
- Parent - An assembly of parts made up of other parts (children).
- Parts Indenture Structure (or Indentured Parts List) - The hierarchical parts breakdown structure for all the parts on an aircraft that will be considered by the VMetric optimization. It includes only parts that significantly affect an aircraft's availability. Therefore it does NOT include non-critical parts or those parts that are quickly and easily repaired or replaced with minimal cost.
- Procurement Lead Time - The time to procure a part from a vendor.
- Repair Lead Time - The time to repair a part at a base, depot or by a vendor.
- Shop replaceable unit (SRU) - The parts that make up an LRU that are removed and repaired in a repair shop.
- Spare - A spare part for an aircraft, stored in warehouses at bases and at the depot.

3.4 Scope

In order to validate the VMetric model methodology in a cost effective and timely manner, several efforts were made to limit the scope of the study. First, the only airframe considered was the HH-60J helicopter. The inventory managers at ARSC determined that it would be the easiest airframe to construct the necessary parts indenture structure in order to run VMetric. It is assumed that the inventory systems for the various airframes behave alike, so if the methodology works for the HH-60J, it should work for the remaining airframes with few modifications. Second, a subset of ten parts were identified to be used in

actual runs of the VMetric model and computer simulation instead of all the parts on the aircraft. These parts were identified by ARSC as being aircraft availability degraders or logistics cost drivers and were chosen because sufficient data were expected to be available to perform the necessary validation. While these parts are not a true random sample taken from the indenture structure, it is assumed that the conclusions reached based on this subset can be extrapolated to all the parts on the HH-60J and the other airframes. They are parts that are managed very closely by ARSC and therefore stocking levels are not far from optimal. If VMetric can improve the logistics system performance with these closely monitored parts, it should improve performance with parts that are less closely watched. Of these 10 parts, there were complete data for eight, so the remaining two parts were eliminated (Hoist and Roll Trim Assembly). Table 1. Lists the subset of parts used in this study.

Table 1. Parts Used for Validation

Nomenclature	Abbreviation	Part No.	NIIN
DAMPENER,VIBR,DR SH	Dampener	70106-28000-048	013470735
SERVO,TAIL ROTOR	TR Servo	70410-26520-042	011585787
TIP,AIRCRAFT	Tip Cap	70150-09107-056	013399308 or 013313845
TACT DATA PROCESSOR	TDP	8901200-529	01hs11346
PITCH TRIM ASSY	Pitch Trim	70410-22760-051	0115855987
BLADE,ROTARY WING	Main Rotor Blade	70150-29100-041	011589679
ELASTOMERIC BEARING ASSY	Elastomeric Bearing	70102-28000-045	011589606
BLADE,ROTARY RUDDER	Tail Rotor Blade	70101-31000-046	011589678

Finally, Air Stations Astoria and Cape Cod were chosen for the field tests. Only two air stations were selected to minimize the disruptions caused by required data collection. The HH-60J is currently operated from eight air stations, Cape Cod, MA.; Elizabeth City, NC; Clearwater, FL.; Mobile, AL.; San Diego, CA.; Astoria, OR.; Sitka, AK.; and Kodiak, AK.

4.0 METHODS

This section describes the methodology used to validate the VMetric model. The details and findings from each step are described in more detail in section 5.0.

Validation of the VMetric model will check to see that the conditions under which VMetric provides an optimal solution are met, and that the assumptions it operates under are valid, or, if not, that the differences between the model and the actual Coast Guard implementation are not significant. It will provide a level of assurance that any changes in stocking levels recommended by the model will result in a spare parts stocking policy that maintains an acceptable level of aircraft availability at minimum cost or achieves maximum availability for a given spare parts funding level. The validation was completed in five main steps.

- Determine if the VMetric Model Assumptions Fit the Coast Guard Aviation Inventory Problem
- Collect Data & Perform Test Runs with the VMetric model
- Test VMetric's Recommended Stocking Levels using Simulation
- Compare Proposed VMetric Stock Levels To Historical Stock Levels using Simulation
- Perform Air Station Field Tests

4.1 Determine if VMetric Model Assumptions Fit the Coast Guard Aviation Inventory Problem

First, the simplifying assumptions that are made in order to apply the VMetric theory were tested to ensure they apply to the Coast Guard's inventory problem. The main assumptions included:

- The actual inventory system is multi-echelon, multi-indentured and structured similarly to the theoretical inventory system assumed by VMetric theory.
- Parts fail according to a Poisson probability distribution.
- Repair times for aircraft parts must be independent and identically distributed (IID)
- When a part fails and is not on hand or repairable at a base, it is immediately shipped to the depot for re-supply. No consolidation of parts to reduce shipping costs is done. In addition, shipping times between bases and the depot are the same for each base and vary only by part type.
- Each base has the same number of aircraft and stock levels

4.2 Collect Data and Perform Test Runs with VMetric

Given that the model assumptions apply to the real world inventory system, the next step was to collect data for all the model input parameters and run VMetric to get a recommended stocking level. This stocking policy was inspected by inventory managers for reasonableness. Performing this step makes sure that the necessary data to run the model are available, for without the required input data, even a valid model would be useless. If the results with the available data were obviously infeasible, then further data collection efforts or a closer inspection of the model could be made.

4.3 Test VMetric's Recommended Stocking Levels Using Simulation

In order to determine if the output from the VMetric model is valid and more importantly useful two approaches were considered.

The first approach was to use the VMetric output to set the spare parts stocking levels for ARSC and each air station and implement them directly in the field. After a specified duration, the resulting system performance could be measured using aircraft availability. If the proposed stocking policy was a good one, availability would increase for the same amount of spare parts funding, or remain the same for a lower funding level. The problems with this approach are obvious. If the stocking policy is poor, the result would be a degradation in aircraft availability which would likely result in an air station not being mission capable. This would pose a threat to life and property which is an unacceptable risk for the sake of testing a new inventory policy. Testing the policy in the field would also be costly and time consuming. Large costs would be incurred to ship parts to and from bases to balance out the stocking policy and procuring recommended parts not yet on hand. These problems forced us to seek an alternative testing methodology.

The alternative approach was to develop a second model to act as a surrogate for the actual logistics system. A computer simulation model was developed to mimic the logistics system. The simulation model was then validated by comparing output data from the simulation to data from the actual inventory system. Validating a simulation model ensures that the model is an accurate representation of the system under study. If the model is valid, then decisions made with the model should be similar to those made by experimenting with the real system.

Once validated, the simulation model was used to perform tests using the recommended stocking levels obtained from the VMetric model. The valid simulation model allows us to "virtually" test proposed stock levels without actually implementing them in the field.

4.4 Compare Proposed VMetric Stock Levels To Historical Stock Levels Using Simulation

Armed with a validated simulation model to take the place of the real world inventory system, tests were performed to determine if the stocking recommendations that VMetric generated were "better" than the stocking policy currently in use.

Stocking policies for the eight selected parts generated by VMetric were compared to historical stocking policies using the simulation model. Three performance measures were used:

- Aircraft availability - The percentage of the time an aircraft was operational
- Base Backorders - The number of times a part failed and was not available at the air station
- Cost of the Stocking Policy - Dollar value of all the parts held in stock at the bases and ARSC

Comparisons focused on comparing the cost and resulting availability of a particular policy. Tests were done to determine how much a VMetric stocking policy would cost to meet the same aircraft availability achieved by a historical stocking policy. Next, simulation runs were done to determine the maximum aircraft availability achieved by VMetric when given the same funding level used for a historical stocking policy. Favorable results would show that VMetric provides the same aircraft availability for lower cost or higher availability for the same costs as the current policy.

4.5 Perform Air Station Field Tests

This final step, a "virtual" field test, provides additional evidence that VMetric provides an improved stocking policy over the current system. Two air stations were selected to participate, air stations Cape Cod and Astoria. The original proposed methodology involved physically changing the stocking levels at the two air stations and ARSC according to the VMetric recommendations. The air stations and ARSC would operate their maintenance and supply processes without change for a period of three months. Analysis of AMMIS data would be used to evaluate the new stocking policy's performance based on aircraft availability. This method was determined to be too costly and time consuming to implement. In addition the threat of a degradation in aircraft availability was considered unacceptable.

The alternative approach was to test the stocking policy "virtually" using an accounting approach. The current stock levels at the selected bases and ARSC would remain the same, however all demands for a subset of parts would be monitored to determine what would have happened had the VMetric stock policy been in effect. If a part demanded at an air station or ARSC is not supposed to be on the shelf according to the test stocking policy but is on hand in reality, it is used, however this event is kept track of in order to account for the amount of time the aircraft should have been down. The time the aircraft would have been down is computed based on estimated repair lead time statistics and this time is subtracted from observed availability. On the other hand, if a part is demanded and it is not on the shelf at the base or ARSC and the part is supposed to be on the shelf according to the test stocking policy, the aircraft will be assumed to be operational even though it is down for repairs in reality. This approach allows us to estimate what would have happened if the VMetric stocking policy was actually implemented.

5.0 FINDINGS AND DISCUSSION

This section describes the methods and results for each of the five steps outlined in section 4.0, accompanied by interpretation and discussion.

5.1 Applicability of VMetric

5.1.1 Structure of the Inventory System

VMetric assumes that an inventory system is structured in a specific manner. The Coast Guard's inventory system must behave according to this structure for the underlying VMetric theory to apply and for the model to work properly. VMetric assumes that when a part fails on an aircraft, it is removed and brought into base supply. If a spare is available it is issued and installed on the aircraft; otherwise a backorder occurs and the aircraft is not available for use. The failed part is taken to the base maintenance shop to determine if it is repairable. This LRU may be disassembled into its component SRU's in order to diagnose and repair the LRU. If it can be repaired it is scheduled for repair and fixed. If the aircraft is still waiting for a part it is issued and installed on the aircraft; otherwise the part is put in inventory at the base. Otherwise the part is sent to the depot (ARSC) and an immediate re-supply request is made. After some re-supply delay, a serviceable unit is received by base supply. If the aircraft is still waiting for a part, it is issued and installed on the aircraft; otherwise the part is put in inventory at the base.

By consulting system experts at ARSC it was determined that the Coast Guard aviation inventory system fits this basic structure very closely. Exceptions include:

- Some parts may be Direct Shipped to repair facilities other than ARSC if the base cannot directly repair them. Direct Shipping of items is done on a minority of high value, high demand items. This can be considered part of the base repair process even though it is not physically being performed at the base, and therefore does not invalidate the model.
- Failed parts are not automatically shipped to ARSC once they fail. They are accumulated for a weekly shipment back to ARSC in a program know as Reverse Shipping. Each station has an assigned day to ship broken material. This fosters disciplined return of repairables and smooths workload spikes at the ARSC warehouse. This is not normally done for a part that is causing an aircraft to be down.
- In some instances such as with the LTS-101 engines, the engine may be repaired on sight by Coast Guard mechanics, repaired on sight by contracted personnel, or Direct Shipped to the LTS-101 repair facility.
- All bases have the same shipping times to the depot depending on the part type. In the actual system the base location causes shipping times to vary by base.

5.1.2 Poisson Demand Assumption

The VMetric model assumes that failures of a part follow a Poisson process. The equivalent statement is that the time between failures for a part is exponentially distributed. This is a common assumption made for mathematical models because the special properties of the Poisson probability distribution can be used to simplify calculations. In VMetric this assumption enables the model to compute the steady-state probability distribution of the number of parts in repair from the probability distribution of the failure process and the mean of the repair time distribution[2].

This assumption was tested using a sample of 10 parts from the HH-60J indenture structure. Demand history for fiscal year 96 for each part was extracted from the AMMIS database and probability distributions were fit to the data[3]. In all but three of the ten items (Tip caps, Hoist, and Tail rotor blade), the time between demands were successfully modeled by the exponential distribution. While the best fit distribution was exponential for only three of the 10 parts, the differences between the best fit distribution and the exponential were not significant when comparing squared errors[4]. Table 2. illustrates the results[5]. Histograms and summary statistics for each fit are located in Appendix F.

Table 2. Failure Distributions for Selected Parts

Part	Distribution Used	P-Value for Distribution Used	Squared Error for Exponential Distribution	Best Fit Distribution	Squared Error for Best Fit
Dampener	EXPONENTIAL(4.25)	.155	.007	Beta	.007
TR Servo	EXPONENTIAL(17)	.005	.003	Exponential	.003
Tip Cap	-0.5 + LOGNORMAL(3.39, 4.56)	.008	.014	Lognormal	.011
TDP	EXPONENTIAL(20.4)	.005	.012	Exponential	012
Roll Trim	0.5 + EXPONENTIAL(28.3)	too few data	.031	Gamma	.030
Pitch Trim	EXPONENTIAL(31.8)	.150	.010	Exponential	.010
Main Rotor Blade	EXPONENTIAL(16.4)	.150	.007	Weibull	.003
Hoist	WEIBULL(44.4, 0.627)	.150	.056	Weibull	.041
Elastomeric Bearing	EXPONENTIAL(7.79)	.221	.019	Beta	.006
Tail Rotor Blade	UNIFORM(1, 25.5)	.165	.062	Uniform	.041

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[2] Sherbrooke, pg. 21
[3] Fitting of distributions was done using the input analyzer function of the ARENA™ simulation software package.
[4] The quality of fit is based on squared error, the sum of the absolute differences between the fitted probability distribution function and the relative frequency of the data for each interval in a histogram of the data. More detail on this procedure is outlined in the ARENA User's Guide, pg. 127.
[5] Either Kolmogorov-Smirnov or Chi Square Goodness of fit tests were done for each part provided sufficient data was available. For the TR servo and the Tactical Data Processor the best fit was exponential but they have a low p value due to small sample sizes of 20. For the Tip cap, the exponential was the 2nd best fit, but it also had a low p value due to high variability observed in the data. The Roll trim was not used in the validation however the exponential was the 2nd best fit. No test was done due to the small sample size of 11.

These results indicate the failure rates for 70% of the parts in the sample can be considered Poisson. Those parts that used other failure distributions did not adversely affect the VMetric stocking recommendations. This indicates that the model appears to be robust enough that relaxing this assumption has no significant effect on the results[6].

5.1.3 Independent Repair Times

VMetric assumes that repair times for parts are independent. This, like the Poisson demand assumption, simplifies the computation of the steady-state probability distribution for the number of parts in repair. The assumption is that when a part fails, it is never affected by the status of repair of any other part; in effect, that parts never queue up for repair. In general this is not a valid assumption and the conclusion would be that VMetric would underestimate repair delays. However, the parts that affect an aircraft's availability are given priority in repair and queues are therefore less influential. For these instances the model probably overestimates repair times. These errors likely cancel each other out. The effect of relaxing this assumption was tested using the simulation model which does not assume independent repair times. Even relaxing this assumption, the VMetric proposed stocking levels improve availability indicating that the independent repair time assumption does not invalidate the VMetric.

5.1.4 Number of End Items Per Base

The version of VMetric used for this validation (version 2.0) forced us to assume that there are an equal number of aircraft at each air station. At the time of our testing, there were on average 31 HH-60J's in the field, so VMetric was run using eight bases with 4 aircraft per base. It was assumed that VMetric would slightly overstate stocking levels due to this constraint. The next version of VMetric is expected to allow different numbers of aircraft per base. This assumption did not adversely affect the results of the VMetric model although the results cannot be considered to be truly optimal. Because of this, care should be taken when implementing the recommended stocking policy. Those bases with a higher than average number aircraft could be given excess parts taken from bases that have a fewer than average number of aircraft.

5.1.5 Lateral Supply

Lateral supply is the practice of sending parts from one air station to another to fill backorders. Lateral supply is only done when a base does not have a part on hand and the depot cannot supply the part in a timely fashion. If another base has the part, it is directed by the depot to send it directly to the requesting base. VMetric is not capable of computing the effect of lateral supply analytically. Instead, it uses a

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[6] VMetric can be configured to account for demand processes that are Poisson with a changing mean and for failures due to wearout. In these cases the variance-to-mean ratios for the demands is shown to be greater than 1 and can be accounted for in the environmental variables prior to running VMetric. See Sherbrooke, pg. 106.

regression approximation developed for simulating lateral supply[7]. In the field, lateral supply is used often and tests were done to see if VMetric's approximations were accurate. The simulation model was used to estimate aircraft availability with lateral supply. Table 3. shows that the VMetric approximations were within 1% of the simulation model results with lateral supply in 11 of 12 tests, and averaged slightly higher than in the simulation model.

Table 3. Comparison of VMetric Availability to Simulation Availability with Lateral Supply

Stock Level	VMetric Availability (Av)*	Simulation Availability (As)	Av - As
$ 1,020,760	58.89%	59.13%	-0.25%
$ 1,507,110	80.05%	79.66%	0.39%
$ 2,061,780	91.18%	92.33%	-1.15%
$ 2,536,130	94.05%	94.22%	-0.17%
$ 3,185,535	96.42%	95.05%	1.37%
$ 3,875,865	97.95%	96.84%	1.11%
$ 4,171,760	98.26%	97.47%	0.79%
$ 4,312,510	98.32%	97.92%	0.40%
$ 4,458,030	98.36%	97.95%	0.41%
$ 4,482,080	98.36%	98.07%	0.29%
$ 6,849,240	98.93%	98.91%	0.02%
$ 7,179,480	98.96%	98.90%	0.06%
$ 10,907,415	99.00%	99.07%	-0.07%

* VMetric Availability was reduced 1% to account for maintenance in the simulation model

5.1.6 Cannibalization

Cannibalization is the practice of consolidating backorders at an air station by taking parts from one aircraft and putting them on another. Cannibalization is used in practice although stocking policies do not normally account for the practice. VMetric can take into account cannibalization with results that are nearly optimal. However, Professor Craig Sherbrooke[8] noted that a stocking policy optimized without a cannibalization assumption was robust even when cannibalization is practiced[9]. While cannibalization is a factor in the field, it is a model assumption that can be relaxed without jeopardizing an optimal stocking policy. Cannibalization was not taken into account in this study.

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[7] Sherbrooke, pg. 224.
[8] Dr. Sherbrooke is the developer of the VMetric theory and serves as a consultant to Systems Exchange Company, the marketers of the VMetric model and other logistics management tools.
[9] Sherbrooke, pg. 173.

5.1.7 Periodic Re-supply

Periodic re-supply occurs when re-supply of failed parts can only be done at specific times. An example of this in the Coast Guard is when helicopters are deployed on cutters. If a required part is not available in the HSK, it cannot be replaced until the next port call or a specially arranged re-supply event. This is a special case that has been considered by VMetric theory and implemented for use on the Space Station Freedom project for NASA[10]. Tests were originally planned to use VMetric with the period re-supply assumption in order to determine an optimal HSK stocking policy. This task was not completed due to time and funding constraints, however a review of the theory shows that VMetric can support this type of analysis.

5.1.8 Redundancy

K-of-N Redundancy is when a system is operational if K of the N subsystems that make up the overall system are operating, where K<N. VMetric models a simple case of redundancy where there is only one aircraft per base and only first indenture parts can have redundant systems. In the Coast Guard there are multiple aircraft at each base and each aircraft can have redundant systems beyond the first indenture so these assumptions do not normally hold. Running VMetric with this option can still be useful for special purposes such as determining the effect on availability of adding redundant systems on one aircraft, but is not helpful for a fleet of aircraft. Not considering redundancy will result in conservative stocking policies that slightly over-estimate inventory needs depending on the number of redundant systems. Redundancy was not taken into account in this study.

5.2 VMetric Test Run Results

Prior to running VMetric to get a recommended optimal stocking policy, all the input variables to the model for the subset of eight parts had to be verified. These input variables consist of a set of "environmental" variables, a set of run time variables, the actual structure of the indentured parts list for just the eight parts, and the part failure rates. Once all these inputs were verified, the model was run to determine an optimal stocking policy.

5.2.1 Environmental Variables

VMetric requires a set of environmental variables that describe the operating and support conditions that pertain to all the parts on an aircraft. The values used for this test are listed in Table 4. along with a brief definition.

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[10] Sherbrooke, Ch 6. Pg. 123.

Table 4. VMetric Environment Variables

VARI-METRIC PARAMETERS	
Maximum Variance-to-Mean ratio	1
Variance-to-Mean Ratio Parameter A	0
Variance-to-Mean Ratio Parameter B	0
DEVELOPMENT/OPERATING PROGRAM	
Operating Systems per Site (integer)	4
Operating Sites (integer)	8
Operating Program (system operating hours / week)	14.59
SUPPORT ENVIRONMENT (2 Echelon)	
Intermediate Maintenance Locations (integer)	0
Orders & Shipping Time: Intermediate to Site (days)	0
Orders & Shipping Time: Depot to Intermediate (days)	0
Orders & Shipping Time: Depot to Site (days)	3
Internal Order Cost (currency / order)	100
Depot Order Cost (currency / order)	500
Holding Cost Rate (ratio)	0.16

- Maximum Variance to Mean ratio - These parameters govern the structure of the demand process distribution for all the parts. For Poisson demand the default is 1.0, and the Variance-to-Mean Ratio Parameters A and B are each 0.
- Operating Systems per Site - The number of aircraft per base. Version 2.0 of VMetric requires each base to have the same number of aircraft. This is an assumption that will cause VMetric to overestimate availability at some bases and underestimate it at others. The net effect should be to cancel each other out and the resulting availability should not be too far from optimal. The next version of VMetric will have the ability to specify exactly the number of aircraft per base.
- Operating Program - The operating program represents the peak operating program hours per aircraft per week. In our case it was determined working backwards from the total HH-60J aircraft operating hours of 24,280 hours taken from the FY96 AICP report[11]. Dividing 24,280 hours by 32 aircraft and 52 weeks per year yields an operating program of 14.59 hours/week.
- Internal Order Cost - Represents the economic cost of preparing and fulfilling an order between the base and the depot.
- Depot Order Cost - Cost of carrying out the purchase of a part from a vendor.
- Holding Cost Rate - Cost of capital, storage space, insurance, pilferage, and obsolescence arising from the investment in spare parts. It is expressed as a fraction, so .16 represents 16% per year. It does not affect the stocking policy, only the recommended reorder points and economic order quantity.

[11] FY96 AICP Report, Aircraft Utilization. Figure III-10, pg. 41.

5.2.2 Run Time Variables

Table 5. lists the data for each part in the VMetric test runs. Data for these inputs were obtained directly from AMMIS or system experts at ARSC. Other input fields are available but were not used in the test runs. The computations for MRR6 are detailed in the following section on part failure rates. The VMetric User's Manual describes these variables in greater detail[12].

Table 5. VMetric Run Time Variables

Part Name	QPA	Item Price	MRR6	MTDs	MTDd	PLT	ADTP	MTBF	DC	RCTs	RCTd
Pitch Trim	1	$30,810	1070.84	0.00	0.90	1	0	0.00	1	0	182
TR Servo	1	$28,360	823.72	0.00	0.90	2	0	0.00	1	0	67
Tail Rotor Blade	2	$24,050	617.79	0.10	0.90	0	0	0.00	1	0.6	165
Elastomeric Bearing	4	$13,250	504.53	0.00	1.00	0	0	0.00	1	0	33.4
Main Rotor Blade	4	$47,860	329.49	0.10	0.80	3	21.3	0.00	1	0.2	107
Tip Cap	4	$5,350	1359.14	0.00	0.90	0	11.9	0.00	1	0	55.5
Dampener	4	$7,480	978.17	0.25	0.75	0	0	0.00	1	0.3	5
TDP	2	$295,895	411.86	0.00	0.99	2	12.2	0.00	1	0	9

- QPA (Quantity per Next Higher Assembly) - The number of this part in its immediate parent.
- Item Price - Price of the item taken from AMMIS
- MRR6 (Maintenance Replacement Rate, per 10^6 hours) - The replacement (failure) rate per million operating hours of one unit of an item on a single aircraft.
- MTDs (Maintenance Task Distribution site) - Fraction of repairs of this part expected to occur at the site (base).
- MTDd (Maintenance Task Distribution depot) - Fraction of repairs of this part expected to occur at the depot.
- PLT (Production Lead Time) - Time required by the manufacturer to produce a replacement assembly (in months).
- ADTP (Administrative Delay Time, Procurement) - Average number of days required for administrative tasks required to procure a replacement part from the manufacturer or other supplier (in days).
- MTBF (Mean Time Between Failure) - Expected interval in hours of operation between failures. Left blank if MRR6 is used.
- DC (Duty Cycle) - The operating time of this item as a fraction of its parent's operating time.
- CRTs (Repair Cycle Time site) - The expected elapsed time in days to repair a part at the site (base).
- RCTd (Repair Cycle Time depot) - The expected elapsed time in days to repair a part at the depot.

[12] VMetric User's Manual,Ch 5 Reference Guide, pg. 57.

5.2.3 One Level of Indenture

Of the eight parts used for this study, all were 1st indenture parts except for the tip cap which is a child of the main rotor blade. These were treated as 1st indenture despite the fact that they are a subassembly to the main rotor blade because they are easily repaired on the aircraft and do not require removing the main rotor blade.

5.2.4 Part Failure Rates (MRR6)

The part failure rate, called the maintenance replacement rate (MRR6), for a part is the most important variable affecting the output of the model. It is the replacement rate per million operating hours of one unit of an item on a single aircraft. If information on the number of items that have failed are not available, the Mean Time Between Failures (MTBF) may be used instead One of these two variables is required for each part.

For the VMetric test runs, MRR6 for each part was computed using the following formula:

$$\frac{Demands/Year}{HH60FlightHours/Year * QPEI} * 10^6$$

Equation 1. Maintenance Replacement Rate

- Demands - Instances of a part replacement
- HH-60J flight hours - Total flight hour per year for the fleet of aircraft
- QPEI (Quantity Per End Item) - Number of this part contained in an aircraft

Table 6. shows the computation of MRR6 for the subset of parts using the number of demands taken from AMMIS for fiscal year 96.

Table 6. Computation of MRR6

Part	QPEI	Demands/Yr	HH-60J Flight Hrs/Year	MRR6
Pitch Trim	1	26	24280	1070.8
TR Servo	1	20	24280	823.7
Elastomeric Bearing	4	49	24280	504.5
Main Rotor Blade	4	32	24280	329.5
Tip Cap	4	132	24280	1359.1
Dampener	4	95	24280	978.2
TDP	2	20	24280	411.9
TR Blade	2	30	24280	617.8

VMetric output includes fields for the number of demands per year for each base and the depot. These figures can be used to check the VMetric output for accuracy against actual data from AMMIS.

5.2.5 Recommended Stocking Policy

After validating all inputs, VMetric was run to get a proposed stocking policy. The output of VMetric shows which part to be purchased, the number to purchase, at which echelon they should be located, the expected availability achieved, and the cost of the stocking policy at each iteration. Figure 1. is a graph of Stocking Policy Cost vs. Average Availability for the test run. Each point on the curve is a potential stocking policy. Its cost is on the x-axis and the expected availability on the y-axis. The actual output of the VMetric run can be found in Appendix C.

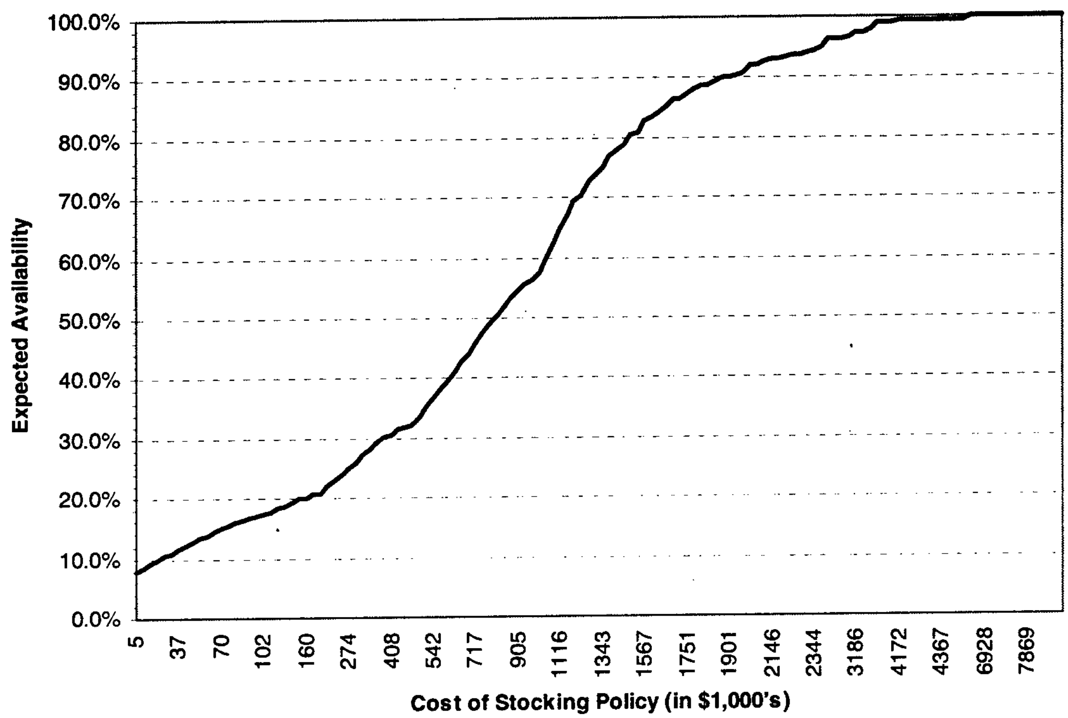

Figure 1. Cost of Stocking Policy Vs. Expected Availability

Table 7. lists two stocking policies taken from the above VMetric output. It lists the number of items to be stocked at the eight bases and at the depot. The $2.9M policy is the closest one to that observed in the field and can be considered a low end estimate. The Max Availability policy is the stocking policy that achieves 100% availability. These policies were compared to the historical stocking policies used in the field.

Table 7. Stocking Policies for Validation

Part Name	$2.9M Scenario (Availability = 96.7%, Cost $2.9M)			Max Availability (Availability = 100%, Cost $ 10.9M)		
	Stock at Each Base	Stock at Depot	Total Stock	Stock at Each Base	Stock at Depot	Total Stock
Pitch Trim	0	19	19	2	22	38
TR Servo	0	8	8	2	9	25
Tail Rotor Blade	1	19	27	2	22	38
Elastomeric Bearing	1	8	16	3	9	33
Main Rotor Blade	0	14	14	2	16	32
Tip Cap	2	26	42	4	28	60
Dampener	1	2	10	3	3	27
TDP	0	1	1	2	3	19

After the VMetric input data was reviewed, the resulting stocking levels were inspected by ARSC system experts and determined to be feasible[13]. The next step was to determine a method for comparing the performance of these stocking levels to that currently being achieved with historical stocking levels.

5.3 Simulation Model Development

The purpose of developing a simulation model of the aircraft logistics system is to have a tool to use to test the effects of VMetric stocking recommendations on the logistics system without actually implementing the changes in the field. Making changes in the field would be costly and could potentially degrade aircraft availability to unacceptable levels.

An aviation spare parts simulation model was constructed for the HH-60J logistics system. The simulation mimics the system of stocking, repairing and procuring spare parts for the HH-60J. Each of the eight airstations with its normal complement of HH-60J helicopters was modeled. Statistics collected include individual aircraft availability, base availability[14], number of backorders at the bases and the depot, the time the aircraft is in a backorder status due to a particular part type, the number of parts due in to the base and depot, and others. The measure used for comparing different stocking policies is aircraft availability. It is computed for each aircraft in the model and then averaged to make an overall

[13] Feasible in this case means that they were not obviously too low. Too high is only a matter of having enough funding available to purchase the required amount of parts.
[14] Probability that at least k of n aircraft are available.

availability determination for the stocking policy. An example of the simulation model output used to compute average availability is given in Appendix E.

The simulation was developed, validated, and used to compare the performance of the stocking levels recommended by the VMetric model to those used in the field today. A thorough discussion of the model development including the conceptual model, model assumptions, validation results, input data used, sensitivity analyses, and a comparison to VMetric output is provided in Appendix A.

5.4 Comparison of Historical Stocking Policy to VMetric Policy

In order to determine whether or not VMetric actually provides better stocking recommendations than historical policies, tests were done using the validated simulation model. Two separate historical stocking policies were tested because there was a large difference between what AMMIS data gave for allowance list stocking quantities and what appeared to be on hand in the field.

The allowance list stocking policy is a high end estimate of how many parts were on hand during FY96 at the bases and ARSC. The number of parts on hand for the bases and ARSC were obtained from AMMIS which gave a total inventory valuation of $13,013,575 (policy H1, see Appendix B). Unfortunately, the bases and ARSC do not normally have their allowance list quantities for these parts, so an AMMIS query for the actual stock on hand during the last 8 months was performed and resulted in a stock policy valuation of $3,054,965 (policy H2, see Appendix B). This is a low end estimate because the AMMIS query did not include parts that were in repair and procurement pipelines. The actual stock level for FY96 would have been somewhere between these two policies and is probably closer to the low end estimate.

When VMetric is run, it provides a list of which part to stock first and where to put it, and continues to do so until a target availability or cost constraint is reached. An example is provided in Appendix C. Each one of these recommendations is a point on the optimal cost vs. availability curve as seen in figure 1. and can be used as a recommended stocking policy. VMetric was run and the 2 stocking level recommendations whose costs most closely matched those of the historical policies were selected and used in the simulation. VMetric achieved 100% availability before recommending a stock level near the valuation of H1. This stocking policy (V1, see Appendix C) cost $10,907,415. The VMetric policy closest in value to H2 cost $2,939,055 (V2, see Appendix C). These two stocking policies were used as input to the simulation and the resulting availabilities were observed[15].

Table 8. shows that for the high end policy (V1 and H1), VMetric provided 0.4% higher availability with $2.1M less stock, a significant improvement in terms of cost savings.

[15] All simulation tests involved 50 replications for 365 days of simulated time with a warm-up time of 200 days.

Table 8. Comparison of Availability for VMetric and Historical Stock Levels (High End)

Policy	Valuation	Availability
V1	$ 10,907,415	99.1%
H1	$ 13,013,575	98.7%
Difference	$ (2,106,160)	0.4%

Further tests were done to determine how much stock would be necessary according to VMetric to meet the historical policy's 98.7% availability. Tests showed that a VMetric stocking policy between $6.85 and $4.48M would achieve similar results. Interpolating between the two values shows that VMetric achieves the same availability as H1 for $7.05M less in stock ($13.01M - $5.96M), a 54% reduction in cost, shown in Table 9.

Table 9. Stock Valuation Required to Meet Historical Availability (High End)

Stock Level	As
$ 4,482,080	98.20%
$ 5,961,555*	98.70%*
$ 6,849,240	99.00%

**interpolated values*

Table 10. shows for the low end policies (V2 and H2), VMetric provided a 4.6% improvement in availability for $115,910 less stock, a significant improvement in terms of availability.

Table 10. Comparison of Availability for VMetric and Historical Stock Levels (Low End)

Policy	Valuation	Availability
V2	$ 2,939,055	95.8%
H2	$ 3,054,965	91.2%
Difference	$ (115,910)	4.6%

Further tests were done to determine how much stock would be necessary according to VMetric to meet the historical policy's 91.2% availability. Tests showed that a VMetric stocking policy between $1.9M to $2.0M would achieve similar results. Interpolating between the two values shows that VMetric achieves the same availability for $1.04M less stock ($3.05M - $2.01M), a 34% reduction in cost, shown in Table 11.

Table 11. Stock Valuation Required to Meet Historical Availability (Low End)

Stock Level	As
$ 1,955,780	88.90%
$ 2,013,298*	91.20%*
$ 2,061,780	93.14%

**interpolated values*

These results clearly indicate that VMetric has the potential to drastically reduce the cost of spare parts and maintain the same aircraft availability, or to increase availability with similar or lower inventory costs.

5.5 Air Station Field Test Results

The purpose of the air station field tests was to determine how the proposed VMetric stocking recommendations would perform if actually implemented in the field. Tests were conducted at air stations Cape Cod and Astoria.

Data were collected on the demand and re-supply events for a 3.5 month period for the subset of 8 parts used in the validation experiments. Both air stations collected data from 1 March 97 until mid June 97.[16] The data included the date and quantity of each demand, if it caused an aircraft to be down, when the backorder was resolved and how it was resolved. This information was sufficient to determine the number and duration of backorders that actually occurred during the test period, then to determine the number and duration of backorders that would have occurred if the VMetric stocking recommendation had been used.

Assumptions made included:

- For both the VMetric and current stocking policies, the number of failures during the period, the procurement and repair lead-times, and part removal/installation times would remain the same. The number of part failures during the period would be different if the proposed VMetric policy was dramatically lower than that used in the field. This is because the aircraft would likely remain in a down state longer, delaying subsequent failures beyond the given test period (because failures occur when the aircraft is being used, not while being repaired for another failure). This was not a problem because the $2.9M VMetric policy used for comparison is based on the sample taken at the air stations and is close to the actual stock policy used in the field.
- Only unplanned failures (demands) were considered, eliminating those demands that occurred due to scheduled maintenance.

[16] Data was collected in real time from the beginning of April - 17 June. Historical data was used to reconstruct the demands and re-supply events that occurred in March using the maintenance log for each aircraft and the associated pink sheets.

The number of backorders and the total time down for all aircraft was computed at each base with the observed data. Next, the number of backorders and expected time down that would have resulted had the $2.9M VMetric stocking policy been used was computed and compared to the observed data.

Air Station Cape Cod experienced six demands for the parts of interest, four of which resulted in backorders resulting in a total of 223.5 hours of aircraft down time. Had the $2.9M VMetric policy been used, there would have been two backorders and a total of 103.5 hours of down time, a reduction in backorders of 50% and a reduction in downtime of 54%. The results are shown in Table 12.

Table 12. Cape Cod Field Test Results

Cape Cod Results	Current ($3.05M) Policy	$2.9M VMetric Policy
Number of Backorders	4	2
Total Hours Down	223.5	103.5

Air Station Astoria experienced 6 demands for the parts of interest, three of which resulted in backorders resulting in a total of 540.7 hours of aircraft downtime. With the $2.9M VMetric policy, there would have been the same number of backorders and aircraft downtime. In this case the VMetric policy equaled the performance of the actual stocking policy. The results are shown in Table 13.

Table 13. Astoria Field Test Results

Astoria Results	Current ($3.05M) Policy	$2.9M VMetric Policy
Number of Backorders	3	3
Total Hours Down	540.7	540.7

Had the $10.9M VMetric stocking recommendation been used, there would have been no backorders or downtime at either air station.

While the data show that VMetric improves or maintains availability, the results are only for a short time period and represent one sample from a probabilistic system. More robust conclusions could be reached from a longer test period of 6-12 months or by collecting historical data for all failures for a year period. Data for these tests are listed in Appendix D.

5.6 Estimated Cost Savings Using VMetric To Maintain Availability

Estimated cost savings based on the subset of parts used in this analysis indicate that between a 34% and 54% decrease in the cost of inventory could be achieved while maintaining the same historical availability levels. These reductions would only apply to those parts used in the indenture structure.

Consumables and items not directly impacting the availability of the aircraft would not be included in these cost savings. Typically, consumables and non-essential items do not make up a large portion of the total stock held for an aircraft. Reducing base stock levels can provide additional savings by reducing several factors including holding costs, parts distribution costs, inventory management workforce levels, spoilage, and investment in storage facility space requirements.

5.7 Estimated Availability Improvement With the Same Funding Levels

VMetric was shown to improve availability given the same amount of funding for spares. The low end VMetric recommended inventory level of $2.9M resulted in a 4.6% increase in availability. The high end historical funding level of $13.01M resulted in an availability of 98.7%. VMetric provided maximum availability (100%-part installation time) with a 16% reduction in inventory cost.

5.8 The Part Indenture Structure

The part indenture structure or indentured parts list (IPL) for an aircraft is an engineering parts breakdown that specifies the hierarchical relationship between all the parts that make up an aircraft. The creation of the IPL is a critical first step in applying VMetric because the hierarchy of parts that comprise a system, and the data associated with each part, serve as the cornerstone for VMetric computations.

Developing this structure for the HH60 was a laborious and expensive task. While AMMIS data tables provide a comprehensive list of parts for the HH-60J, they do not reflect the hierarchical relationship between parts necessary to construct the IPL. In order to create the IPL, ARSC inventory management personnel, Sikorsky technical representatives, and Systems Exchange software engineers had to carefully match data from AMMIS to data from other sources. As an example, in order to correctly place some parts within the indenture structure, the Sikorsky's Illustrated Electronic Technical Manual (IETM) was used as a reference to identify the assembly/sub-assembly relationship between parts. Once identified, these parts were then cross referenced to the original equipment manufacturers part number in AMMIS. In this way the linkage between a part in AMMIS and its correct placement in the indenture structure for the HH60J could be derived.

Some of the data were mapped electronically into the IPL by Systems Exchange[17] personnel. Most of the structure, however, was manually entered into the VMetric model. Constructing the IPL only needs to be completed once per airframe, however it will require updates when new parts are introduced to the airframe or when it is reconfigured. It will also have to be updated anytime the supporting data changes.

To limit the scope of the manual indenture project, it was critical to limit the detail included in the indenture structure. Breaking down the aircraft to its smallest part is not necessary and a reasonable judgment had to be made concerning the level of indenture to include. Many common hardware

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[17] Systems Exchange is a private company that markets the VMetric model.

consumables were included, though those items $50 and below were filtered out before running VMetric to simplify the overall system. They can be included as the indentured structure is refined in the future. As a rule of thumb, Sherbrooke recommended future indenture structures be detailed only to the third level of indenture.

5.8.1 Data Sources

Data was assembled from several sources. The aircraft manufacturer's LSA-036 report, which details the material used to build the aircraft, was used for default values. The Navy's parts database at the NAVICP was used to provide cross reference data and the latest part numbers available. AMMIS was used to provide costs, parts currently in use, and demand data. The majority of the data came from the HH-60J Illustrated Parts Breakdown which is a technical manual used by mechanics and engineers to repair the aircraft and from AMMIS. The data sources used to create the IPL included:

- AMMIS: AMMIS data provided by ARSC on 5/17/96. This data was from a query tailored to support VMetric input.
- USCG2_17: AMMIS data which provides up to date part cost, and manually computed MRR6 data for multiple systems.
- LSA-O36 Report: This electronic report is data provided by Sikorsky with some additional fine tuning by ARSC and Systems Exchange. This file is based on the LSA-036 Provisioning Requirements data and is used to provide reasonable default values for parts where no data exists or is missing. The LSA-036 Provisioning Requirements provides data used in the selection procedures to identify repair parts requirements in support of equipment in the field. The LSA-036 is a report included in the Military Standard, DOD Requirements for a Logistics Support Analysis Record.
- HH-60J Illustrated Parts Breakdown Technical Manual
- NAVICP parts database - Provided all part numbers that cross reference to a Sikorsky part number
- Sikorsky - Logistics representative, HH-60J Illustrated Electronic Technical Manager (IETM). The IETM was useful for identifying parts known to have significant demand in the field, but not reflected in AMMIS.
- ACMS - Aviation Computerized Maintenance System

5.8.2 Data Integrity

Running VMetric without checking and maintaining the quality of input data can lead to disastrous results. Every part that is identified for VMetric input should be re-checked for correct placement within the IPL, and for the accuracy of its related data items (MTBF, unit price, PLT, etc.). Some of the problems encountered when constructing the IPL included:

- Missing Part Data - Some parts in AMMIS did not map into the IPL because the part numbers did not match due to old or superseded part numbers. An attempt was to provide the latest part number which may not have been placed in use by the Coast Guard at the date of the indenture.
- Inaccurate data - The MRR6 computation used in the USCG2_17 data does not include adjustment for the total quantity of the part fitted to all aircraft. Nor does it include total number of flight hours

for all aircraft for multi-system parts[18]. MRR6 will have to be calculated on a part by part basis for systems used on multiple airframes.

- Multi-System Data - Since the IPL was constructed only for the HH-60J, the information had to be specific to that system only. Therefore the multi-system parts associated with the HH-60J had to be determined.

5.8.3 Integrating the IPL into VMetric

Integrating the required model data from AMMIS to the IPL and then into VMetric is a non-trivial task which requires careful attention in order for VMetric results to be valid. It is possible that with ARSC personnel and contractor support, this phase of the implementation could be accomplished quickly. A three step approach for completing the VMetric implementation is presented below:

(1) Resolve VMetric data issues by incorporating only a subset of the IPL.

(2) Run VMetric and evaluate the quality of the results. Repeat step 1 if the results are unrealistic.

(3) Add more parts using specific management criteria, such as filtering out all parts with a cost below $500. Repeat step 2 until all parts desired for inclusion have been incorporated.

[18] Parts used on multiple airframes.

6.0 CONCLUSIONS

This validation effort has found that the VMetric model assumptions fit the Coast Guard aviation logistics system and that the model can provide significant cost savings or availability improvements if implemented for the HH-60J airframe.

6.1 Model Assumptions

The structure of the Coast Guard aviation spare parts logistics system is very close to that assumed by VMetric theory with relatively minor exceptions. The most important assumption, that failures follow a Poisson distribution, was found to be sufficiently met by 70% of the parts tested, and the remaining 30% did not significantly affect the model output. The independent repair time assumption was found not to hold in the field; however simulation tests indicated this assumption may be relaxed without invalidating the model output. Version 2.0 of VMetric forces all bases to have the same number of aircraft. This assumption, while not true in practice, did not result in a significant overstatement of availability by VMetric. This assumption should be taken into consideration when actually assigning new stock levels by manually adjusting them based on the true number of aircraft at a base. Lateral supply is practiced in the field and the VMetric approximations of availability with lateral supply were found to be accurate. Optimizing stock policies with a cannibalization assumption is not necessary and can be ignored. Tests to determine an optimal Helo Support Kit using VMetric's periodic re-supply feature were not completed due to funding and time constraints. Version 2.0 of VMetric is not capable of adequately modeling redundancy for Coast Guard purposes.

6.2 Simulation Model Validation

A simulation model of the spare parts logistics system for the HH-60J was developed in order to compare the performance of VMetric stocking recommendations to historical policies used in the field. The model was successfully validated using total number of base level backorders and total number of failures of each part type for FY96. Results for both measures were compared to FY96 AMMIS data and reviewed by ARSC system experts. The AMMIS data for number of backorders fit within a 95% confidence interval for three of eight parts. The remaining parts all had values that fit within the simulation model's high and low range and were sufficiently close to seem plausible to ARSC system experts. Sensitivity analysis of the model inputs showed it performed as expected, further supporting the model's validity. In addition, the output of the VMetric model and the simulation model were compared when given the same inputs. The results showed that the two models provided availability estimates that were typically within 1% of each other.

6.3 Model Performance

The VMetric proposed stocking recommendations were compared to historical stocking policies using the validated simulation model. Two historical policies were tested, the first was based on the allowance list levels for parts at the bases and the depot and was valued at $13.01M. The second was a policy based on a sample taken of on hand inventories over a period of eight months and was valued at $3.05M. These policies were compared to two corresponding VMetric stocking policies of $10.90M and $2.94M respectively. VMetric was able to achieve the same availability (98.7%) as the $13.01M stock policy for $7.05M less in stock, a 54% cost savings. When compared to the $3.05M policy, VMetric achieved the same availability for $1.04M less, a 34% cost savings.

6.4 Air Station Field Tests

Field tests performed at air stations Cape Cod and Astoria showed that for a limited test period of 3.5 months, the VMetric stocking recommendation of $2.94M provided better or equal results with respect to aircraft availability than the current stocking policy. Comparing the current stocking policy to the VMetric recommendation at Cape Cod, there were 4 vs. 2 backorders for a total of 217 vs.145 hours of downtime, a 33% reduction. At air station Astoria, the two policies resulted in the same number of backorders and hours of downtime. Due to the limited time frame of the data collection, these results are not robust. A 6 month to 12 month period would provide better data for robust conclusions.

7.0 RECOMMENDATIONS

This project has shown that the VMetric model has the potential to reduce current stocking levels for the HH-60J airframe by a third to a half without degrading aircraft availability. The VMetric implementation for the HH-60J currently in progress at ARSC should be continued. VMetric has the potential to improve the spare parts logistics system for all of the Coast Guard airframes and possibly the cutter fleet as well.

7.1 Initial Implementation for the HH-60J

The VMetric model should first be completely implemented for the HH-60J airframe and tested in the field prior to expanding its use to the other airframes. While the indenture structure has already been created, data integrity for all critical parts should be verified prior to running the model. In particular, forecasted demand rates used to compute MRR6 should be verified as they are the most influential input variables in the model. The next version of VMetric which allows different numbers of airframes per site should be used. The lessons learned in implementing VMetric for the HH-60J should be applied to subsequent airframes.

7.2 Implementation For All Aircraft

Once the model has been proven to be effective in the field for the HH-60J, the HH-65A, HU-25 and HC-130 should be added. Contractual support to develop an indenture parts structure that is sufficiently detailed but not overly complex for each airframe should be the goal. No more than three levels of indenture is a rough estimate according to Sherbrooke. VMetric does not take into account scheduled maintenance unless the demands for parts used in maintenance were included in the computation of MRR6. Scheduled maintenance should be left out of the VMetric computations, and instead should be planned for separately because the demands are known in advance. While all model assumptions need not be re-investigated for each of the subsequent airframes, care should be taken to ensure that the structure of the logistics system fits the VMetric theory as was done for the HH-60J. If the new airframes follow the same logistics system structure, the current version of the simulation model may be used to test the recommended VMetric policies prior to implementing them in the field in a manner similar to that done in this project.

7.3 Development Of An Optimal HSK

While time and funding constraints prevented exploring the use of VMetric to determine an optimal HSK, it was determined that VMetric does have the capability to optimize stocking policies for this type of system. Using Periodic re-supply, part weight, volume and criticality, VMetric can be used to develop an optimal HSK. Tests similar to the "accounting" done for the field tests with Cape Cod and Astoria could be used to test the performance of the proposed VMetric HSK prior to actually implementing it in

the field. Air Station Clearwater performed two data collection efforts during SEABAT deployments however operation Frontier Shield canceled all SEABAT deployments and permanently stopped data collection efforts.

7.4 Applicability To All CG Assets

Once established in the aviation community, VMetric should be applied to any other logistics system in the Coast Guard that fits the assumptions. Further research should be done to determine if VMetric can be applied in the surface community to manage spare parts.

7.5 Using VMetric to Manage Spares

Using VMetric to manage an inventory system does not involve running the model once and forgetting about it. It is a process that must be updated on a regular schedule and experimented with. VMetric will not continue to provide optimal stocking policy recommendations if the inputs to the model become obsolete. A methodology for updating input variables and re-running the VMetric model should be developed. Systematic updates will take into account changes in the logistics system and structure of the airframe early enough to prevent drastic changes in stock levels with each update run of VMetric. It is essential that all inputs are re-validated before each run to prevent optimizing for an outdated system. A methodology for mapping AMMIS data to VMetric inputs automatically should be initiated to ensure input data integrity when running VMetric.

VMetric can be applied to solve inventory related applications beyond just computing an optimal stocking policy. It can be used to:

- Determine if contractor estimates for a spare parts budget to maintain a new airframe are on target or not. It can also be used to determine an optimal value for the initial buy of spare parts for a new airframe.
- Perform what-if analyses beyond recommending optimal stock levels. For example, it can be used to identify the items that contribute the most to the cost of inventory and then determine the effect of proposed changes in the supply system to deal with those parts. Reducing repair lead-times or the percentage of those parts repairable at the base level can be tested to determine if those changes to the system are cost-effective.
- Develop an optimal HSK as described above.

8.0 REFERENCES

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Appendix A SIMULATION MODEL DEVELOPMENT AND VALIDATION

The purpose of developing a simulation model of the aircraft logistics system is to have a tool to test the effects of VMetric stocking recommendations on the logistics system without actually implementing the changes in the field. Making changes in the field would be costly and could potentially degrade aircraft availability to unacceptable levels.

An aviation spare parts simulation model was constructed for the HH-60J logistics system. The simulation was written in ARENA™, a discrete event simulation software package based on SIMAN. The simulation mimics the system of stocking, repairing and procuring spare parts for the HH-60J. This model was developed, validated, and used to compare the performance of the stocking levels recommended by the VMetric model to those used in the field today.

This appendix describes the simulation conceptual model, assumptions made, validation efforts, and sensitivity analyses performed. It also outlines the calibration of the simulation model output to the VMetric model output. Finally, it presents suggested ways the model can be used to better manage the spare parts logistics system.

Conceptual Model

The simulation follows the basic procedures used for stocking, repairing and re-supplying spare parts to aircraft in the field. There are two echelons, the base (an air station) and the depot (ARSC). Parts are stored at each location. Repairs can be effected at either the base or the depot depending on the part. Procurement of parts is done from the depot only.

When a part fails on an aircraft, if a spare is available it is issued and installed on the aircraft; otherwise a backorder occurs and the aircraft is not available for use. The failed part is taken to the base maintenance shop to determine if it is repairable. If it can be repaired it is scheduled for repair and fixed and put back on the aircraft if it is still down, or put on the shelf; otherwise it is sent to the depot (ARSC) and an immediate re-supply request is made of the depot. After some delay for supply, a serviceable unit is received by the base. If the aircraft is still waiting for a part, it is issued and installed on the aircraft; otherwise the part is put in inventory at the base.

At the depot, if the part is on hand, it is immediately shipped to the requesting base. If the part is not on hand and is causing a backorder, a check is made to find the part at another base. If located, the new base ships the part directly to the requesting base to fill the backorder. If the part is not on hand, no other base has the part and the part must be procured, a new part is procured and sent to the base upon arrival. If the part can be repaired, the depot waits for the carcass to arrive and if repairable, fixes the part and ships it to the requesting base. If the part is not repairable, it is scrapped and a new one procured.

These processes were verified by the inventory managers and system experts at ARSC and are outlined the flow diagrams for the base, Figure A-1, and the depot, Figure A-2.

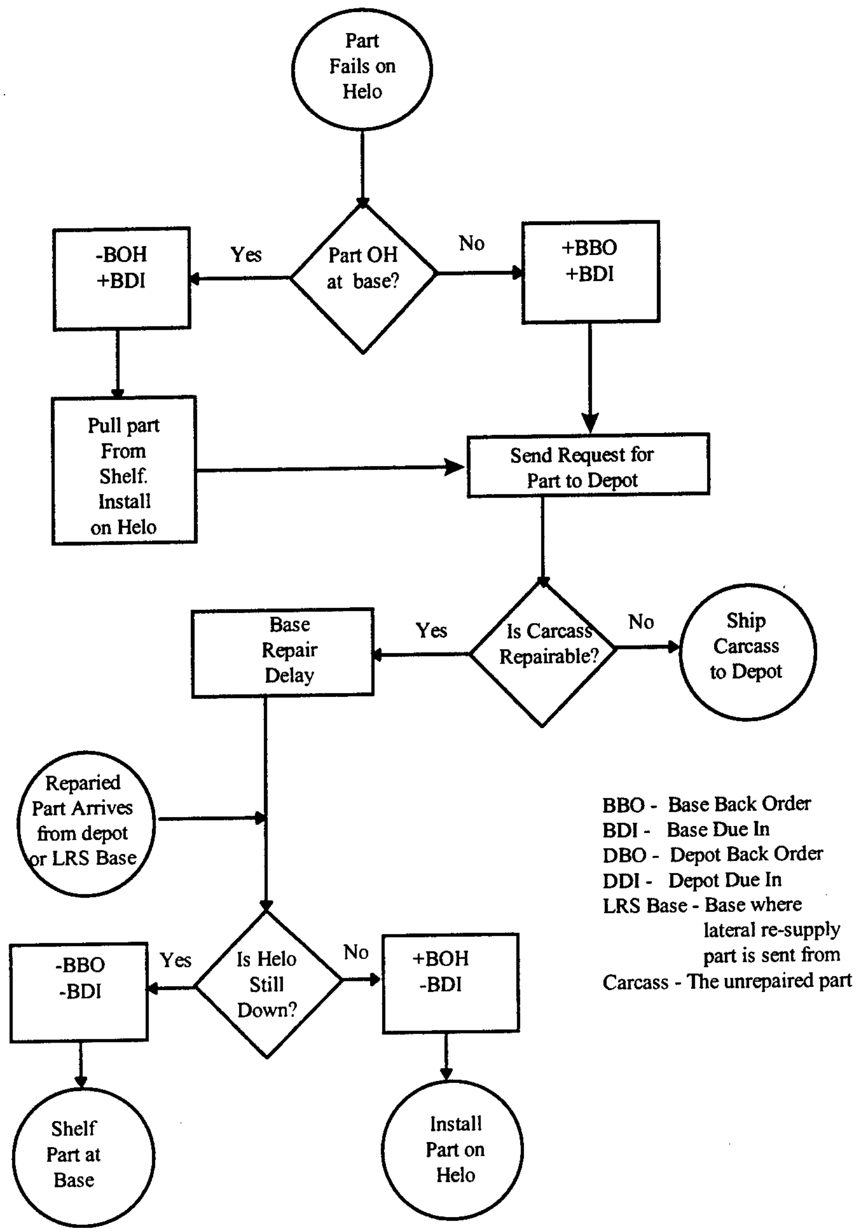


Figure A-1. Base Logic Flow Diagram

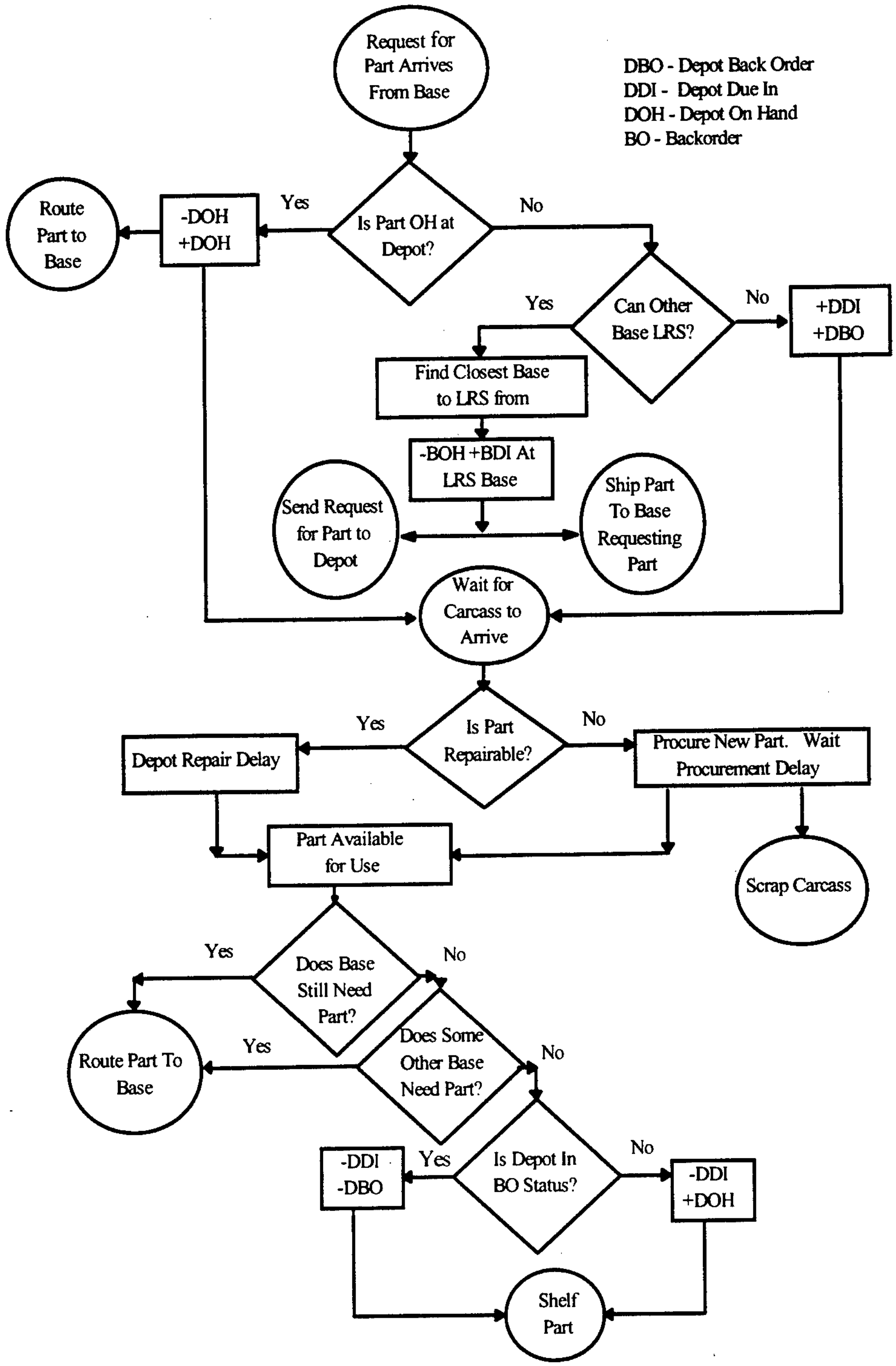


Figure A-2. Depot Logic Flow Diagram

There are eight air stations with HH-60J helicopters. Each was modeled with it's normal complement of aircraft.

The model collects a number of statistics including individual aircraft availability, base availability, number of backorders at the bases and the depot, the time the aircraft is in a backorder status due to a particular part type, the number of parts due in to the base and depot, and others. The measure used for comparing different stocking policies is aircraft availability. It is computed for each aircraft in the model and then averaged to make an overall availability determination for the stocking policy.

Assumptions

As with any mathematical model, assumptions are made to simplify the simulation problem. The following assumptions are made in the simulation.

- Only the subset of 8 parts from of the HH-60J indenture structure were used for the simulation model. Because of this assumption, the simulation model computes an availability that results from just those 8 parts, assuming the remaining parts on the aircraft never fail. Therefore this availability is associated only with the subset of parts and cannot be directly compared to the availability figures obtained from AMMIS which considers all parts. An attempt was made to obtain the availability that results from a subset of parts by using data from AMMIS and ACMS. This failed because aircraft availability is computed by determining if the aircraft is up or down without noting specifically for the part causing the downtime.
- Parts fail one at a time on an aircraft. If an aircraft is down, additional parts cannot fail on it until it becomes operational again. This assumption is based on the fact that parts generally fail from use, and if the aircraft is not flying, wear and tear is not accumulating. In the field, multiple parts can simultaneously cause aircraft failure. This assumption, while not valid in the field did not significantly affect the simulation model output.
- The failure rate for parts is the same for each air station and each aircraft. While some bases have different operating hours and environments, the effects of the difference in failure rates are considered negligible when considering overall aircraft availability.
- Lateral Supply is used only when an aircraft is down due to a backorder and neither the base nor the depot has the part on hand. In these instances, a base with the needed part that is the closest in terms of shipping time to the requesting base will send the part to the requesting base.
- Scheduled maintenance is not modeled. This assumption required the demand data to be purged of all routine parts requests. Demand data was obtained only for priority 2 orders from the bases and used for the demand rate. This eliminated requests for parts that were to supply the base for 600 hour inspections and other scheduled maintenance actions.
- Part installation times are modeled. The times were obtained from interviews with air station EO's.
- If a part causes a backorder, all shipments will occur via the fastest means possible in order to speed up the repair process so FEDEX shipping times were used.
- There is a one-for-one repair/procurement policy meaning the bases never consolidate shipments in order to save on shipping costs. This is a valid assumption for the high priority requests that are modeled in the simulation because these parts are critical to the operation of the aircraft and will be immediately shipped to and from bases without delay.
- Cannibalization is ignored.

Validation Results

Verify the Conceptual Model

The conceptual model was verified by soliciting input from system experts. A workshop was conducted with key members of the ARSC staff and the base flow diagrams were presented for comment. Changes were incorporated to the simulation model. While collecting input data for the simulation model, interviews were made with inventory managers, item managers, air station engineering officers, and others in the supply process to ensure the model logic was correct.

Input Data Used

The input data used for the simulation were taken directly from AMMIS or provided by system experts at ARSC and various air stations. The simulation requires the following inputs:

- The stocking policy for spare parts which consists of the inventory level for each part held at each of the eight bases and the depot.
- The failure (demand) rate for each part. These are in the form of a probability distribution based on AMMIS data.
- The Repair and Procurement times for each part. These are in the form of probability distributions based on AMMIS data.
- Shipping times for parts between the bases and ARSC and from base to base.
- Repair times for parts at the base
- Remove and install times for parts at the base
- The probability of repairing a part at the base or depot
- The probability of scrappping a part that is not repairable

The specific inputs used for the validation are listed in Appendix B.

Compare Output to Historical Data

Original plans were to use aircraft availability as a measure to validate the simulation model. Unfortunately it is impossible to determine the contribution to aircraft availability caused by a particular subset of parts by using AMMIS and ACMS data. To use availability to validate the simulation model it would be necessary to model every part on the HH-60J that can cause backorders. This was infeasible and instead, the number of base backorders in a year was chosen to validate the model. Validation of the simulation model was done using backorder data and the total number of failures observed in a year taken from FY96 AMMIS data.

After all inputs to the simulation model were verified by ARSC personnel for accuracy, the simulation was run with the stocking level from Table B-1 in Appendix B[1]. The total number of backorders was recorded and compared to what was actually observed in AMMIS during FY96. If the model inputs were accurate and the model valid, the simulation should output a similar number of backorders per year as observed in the FY96 AMMIS data.

The simulation output for the number of backorders at the bases is listed in the table below. The AMMIS data used for comparisons included only the priority 2 backorders and eliminated redundant failures (those instances when more than one of a particular part type failed on the same aircraft on the same day). This adjustment was necessary because the simulation only allows one part to fail at a time on the aircraft.

Table A-1. Number of Base Level Backorders

PART	SIMULATION VALUE	MINIMUM VALUE	MAXIMUM VALUE	AMMIS VALUE
Dampener	51.0 ± 2.8*	34	81	44
TR Servo	6.1 ± .9	1	14	9
Tip Cap	40.6 ± 6.8	10	110	35*
TDP	10.6 ± 1	4	17	11*
Pitch Trim	8.9 ± .9	1	18	9*
Main Rotor Blade	13.3 ± 1.6	4	27	20
Elastomeric Bearing	7.7 ± 1.4	1	23	11
Tail Rotor Blade	20.7 ± 1.6	7	30	16

* AMMIS value for number of backorders in FY 96 falls within the 95% confidence interval resulting from 50 runs of the simulation model

Examination of Table A-1. shows that three of the ten parts actually had AMMIS values that fell within the 95% confidence interval for the average number of backorders. Of the remaining parts, the Main Rotor blade backorders were on average 6.7 parts lower than observed in AMMIS however it fell within the minimum and maximum values for the 50 simulation runs. The simulation output cannot be compared statistically to the actual AMMIS value because the AMMIS value is merely one instance in a probabilistic process. Despite this fact, the results are remarkably close and were considered plausible by system experts, supporting the validity of the simulation model.

In addition, the number of failures per year for each part in the simulation model was compared to that taken from FY96 AMMIS data. Table A-2. gives the average value taken from the simulation model and compares it to AMMIS data. The results are very close, the largest difference occurring in the Pitch trim

[1] This was determined to be a terminating simulation. A warm-up time of 200 days was used and statistics were collected for a one year period. 50 replications were made for each "run" of the simulation model.

assembly. The time between failures for this part were highly variable and could explain the difference when compared to a single data point taken from FY96 AMMIS data.

Table A-2. Comparison of Simulation Failures to AMMIS data

Part	Average Value	Min	Max	Actual No. of Failures in FY96 (From AMMIS)
Dampener	84.7	67	121	95
TR Servo	19.9	11	31	20
Tip Cap	127	84	157	132
TDP	17	8	28	20
Pitch Trim	10.8	5	19	26
Main Rotor Blade	22.8	14	33	32
Elastomeric Bearing	47.1	35	58	49
Tail Rotor Blade	27.4	22	33	30

Sensitivity Analysis

Sensitivity analysis explores how model output is affected by changes in inputs. This is a helpful step in the validation of a model because it ensures the model responds to input changes in a logical manner. If anomalies are discovered, they can be investigated to ensure there is not an error in the model. Analyses were done on several input variables including: changes in stock levels, procurement and repair lead times, the effects of lateral supply, failure rates for parts, shipping time changes, and the effects of simulation warm-up time.

Sensitivity analyses were performed with respect to all these variables using both the VMetric $2.9M stocking policy and the historical $3.05M stocking policy. The VMetric policy proved to be more robust in that the same input changes resulted in a smaller changes in availability in virtually all cases. Table A-3 summarizes the results.

Table A-3. Sensitivity Analysis, Comparison of VMetric to Historical Stocking Policy

Scenario Description	Difference from Baseline Availability for Historical Policy $3.05M (A = 91.22%)	Difference from the Baseline Availability for VMetric Policy $2.9M (A = 95.82%)
Repair & Proc Lead-times +10%	-2.82%	-0.32%
Repair & Proc Lead-times -10%	1.34%	0.28%
Lateral Supply & Base to Depot Times +1 day	-2.01%	-1.42%
Lateral Supply & Base to Depot Times +2 days	-4.45%	-2.22%
Lateral Supply & Base to Depot Times -1 days (min 1 day)	1.80%	1.31%
Lateral Supply & Base to Depot Times -2 days (min 1 day)	1.26%	1.28%
Base Repair Prob. increased 10%	2.07%	0.19%
Base Repair Prob. decreased 10%	-3.20%	-0.58%
Scrap Rate Prob. increased 10%	-0.15%	-0.06%
Warm-up time 300 days	-2.58%	-0.31%
Warm-up time 400 days	-3.24%	-1.02%
Failure Rate decreased 10%	2.34%	0.89%
Failure Rate increased 10%	-4.55%	-0.93%

Stock Level

Tests with different stocking policies were done when comparing the VMetric output to historical stocking policies and when performing the tests for lateral supply described previously. In all cases, addition of stock increased availability, and decreasing stock reduced availability as expected. As stock levels decreased to minimum levels, small changes in the number of parts had a large effect on the number of backorders that would occur. Changes in stock had less of an effect for high cost stock policies. No counter-intuitive results were found while experimenting with stock level changes.

Procurement and Repair Lead-times

Procurement and Repair Lead-times were varied ± 10% from the baseline values used for the validation runs. Availability was shown to be inversely proportional to changes in repair and procurement lead-times. The effects of the changes on the historical policy were more pronounced that those for the VMetric policy. Table A-4 summarizes the results.

Table A-4. Sensitivity Analysis, Repair and Procurement Lead-times

Scenario Description	Summary historical levels $3.05M	Difference from Baseline	VMetric Policy $2.9M	Difference from Baseline
Baseline Availability	91.22%		95.82%	
Repair & Proc Lead-times +10%	88.40%	-2.82%	95.50%	-0.32%
Repair & Proc Lead-times -10%	92.55%	1.34%	96.10%	0.28%

Lateral Supply

Lateral supply was found to improve availability as expected. As stock levels increased, the effectiveness of lateral supply decreased as indicated in figure A-3. which depicts the difference in availability (With lateral supply - Without lateral supply) as the cost of the stocking policy increases.

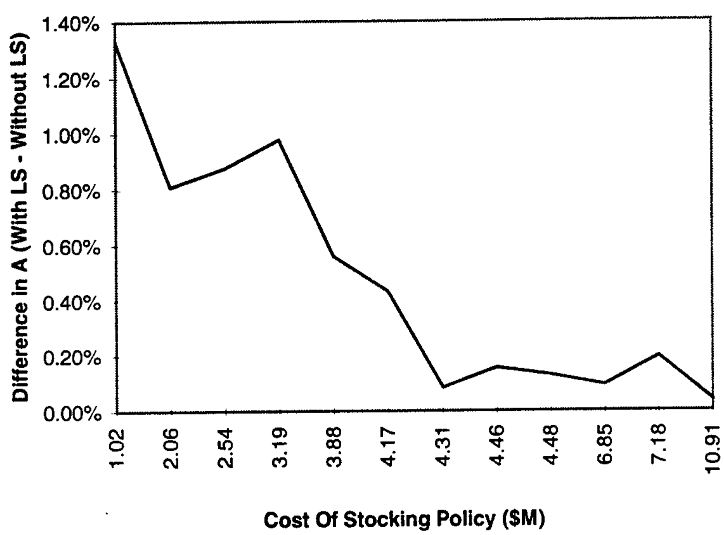


Figure A-3. Difference in Availability Due to Lateral Supply

Failure Rates

Failure rates were varied ± 10% from the baseline used for the validation runs. Availability was shown to be inversely proportional to changes in part failure rates. The effects of the changes on the historical policy were more pronounced that those for the VMetric policy. Table A-5 summarizes the results.

Table A-5. Sensitivity Analysis, Failure Rates

Scenario Description	Summary historical levels $3.05M	Difference from Baseline	VMetric Policy $2.9M	Difference from Baseline
Baseline Availability	91.22%		95.82%	
Failure Rate decreased 10%	93.56%	2.34%	96.71%	0.89%
Failure Rate increased 10%	86.67%	-4.55%	94.89%	-0.93%

Shipping Time

Shipping times between bases and ARSC and from base to base were varied ± 2 days in one day increments. The minimum shipping time used was 1 day. Availability was shown to be inversely proportional to changes in shipping times. The effects of the changes on the historical policy were more pronounced that those for the VMetric policy. Table A-6 summarizes the results.

Table A-6. Sensitivity Analysis, Shipping Times

Scenario Description	Summary historical levels $3.05M	Difference from Baseline	VMetric Policy $2.9M	Difference from Baseline
Baseline Availability	91.22%		95.82%	
Lateral Supply & Base to Depot Times +1 day	89.21%	-2.01%	94.40%	-1.42%
Lateral Supply & Base to Depot Times +2 days	86.76%	-4.45%	93.60%	-2.22%
Lateral Supply & Base to Depot Times -1 days (min 1 day)	93.02%	1.80%	97.13%	1.31%
Lateral Supply & Base to Depot times -2 days (min 1 day)	92.48%	1.26%	97.10%	1.28%

Warm-Up Time

Warm-up time in a simulation model is the time it takes for the system to reach a steady state prior to collecting statistics of interest. It is important to ensure the model is warmed up to avoid excessive variation in the output data. A graphical analysis of average availability was used to determine a warm-up period of 200 days for the model. Tests were done to determine the effects of longer warm-up periods on availability. Increasing warm-up time with the VMetric policy not change availability significantly however w/ the historical policy it appeared that availability decreased approximately 3%. Further analysis was done to determine if this difference was statistically significant. Using a paired-t test to compare individual aircraft availability with a warm-up period of 200 days to that of availability with a

warm-up period of 400 days showed no statistically significant difference in the scenarios[2]. Table A-7 summarizes the results.

Table A-7. Sensitivity Analysis, Warm-Up Time

Scenario Description	Summary historical levels $3.05M	Difference from Baseline	VMetric Policy $2.9M	Difference from Baseline
Baseline Availability	91.22%		95.82%	
Warm-up time 300 days	88.64%	-2.58%	95.51%	-0.31%
Warm-up time 400 days	87.98%	-3.24%	94.80%	-1.02%

System Experts Review Output for Reasonableness

System experts at ARSC were used to validate the output of the simulation model. The inventory managers were consulted to verify that the logical flows used to process spares was an accurate representation of the real system. In addition they were asked to determine if the base backorder figures used for validation purposes were plausible. This was an iterative process culminating with the final validation runs. Although many changes to the model were made in the process, the final version used for validation provided results that were remarkably close to historical data taken from AMMIS and passed the expert review of individuals familiar with the real-world system.

Comparison Of VMetric Output To The Simulation Model Output

This step in the simulation model development was used to calibrate the simulation model and the VMetric model. At this point, the simulation model was considered valid and it's output was compared to the VMetric model to see if there were any systematic differences in the two models. In the ideal case, if both models use the same inputs, they should yield similar outputs and differences will be caused by variations in model assumptions rather than errors in implementation.

Inputs to both models were synchronized and VMetric was run for an unlimited stock valuation. Next, 10 different stocking policies were taken from that output and were run through the simulation. The resulting average aircraft availability was compared to that given by the VMetric model. VMetric provides availability figures for stocking policies with lateral supply and without. This test was done using the simulation model with and without Lateral Supply to check how VMetric and the simulation model correspond to the two different systems.

Comparisons of VMetric availability (Av) and the simulation model availability (As) show that the two models correspond within 1% with respect to availability with lateral supply and without. The difference

[2] Paired-t test comparisons were conducted for all 31 aircraft. For all tests, there was not enough evidence to say mean availability was different for the two warm-up time scenarios at the 95% confidence level.

can be explained by several differences in model assumptions. First, VMetric assumes 4 aircraft are at each site when in fact there are 3 at some and one even has 7. This will tend to have VMetric overestimate availability because there is less variability in VMetric's version of the system than in the real system. Second, VMetric does not take into account the time to install parts as the simulation model does. Therefore the availability that VMetric outputs should be considered an availability due to spares only. A test was made using the simulation model to determine how much installation time affects availability. It was shown that when the simulation was run using extremely high stocking levels so that no backorders ever occurred, the resulting average availability was 99%. So the time it takes to install parts degrades availability by approximately 1% and this should be subtracted from the availability that VMetric outputs. The table below lists the results from these tests on 10 different stocking levels.

Table A-8. Comparison of VMetric Model and Simulation Model Availability Output

	With Lateral Supply				Without Lateral Supply			
stock level ($M)	Av	Av adj (Av - 1%)	As	Av adj - As	Av	Av adj (Av - 1%)	As	Av adj - As
$ 1.02	61.65%	60.65%	60.46%	0.19%	59.89%	58.89%	59.13%	-0.25%
$ 1.51	83.34%	82.34%	79.45%	2.89%	81.05%	80.05%	79.66%	0.39%
$ 2.06	93.69%	92.69%	93.14%	-0.45%	92.18%	91.18%	92.33%	-1.15%
$ 2.54	96.28%	95.28%	95.09%	0.19%	95.05%	94.05%	94.22%	-0.17%
$ 3.19	98.32%	97.32%	96.03%	1.29%	97.42%	96.42%	95.05%	1.37%
$ 3.88	99.24%	98.24%	97.40%	0.84%	98.95%	97.95%	96.84%	1.11%
$ 4.48	99.65%	98.65%	98.20%	0.45%	99.36%	98.36%	98.07%	0.29%
$ 6.85	99.93%	98.93%	99.00%	-0.07%	99.93%	98.93%	98.91%	0.02%
$ 7.18	99.96%	98.96%	99.10%	-0.14%	99.96%	98.96%	98.90%	0.06%
$ 10.91	100.00%	99.00%	99.11%	-0.11%	100.00%	99.00%	99.07%	-0.07%

Uses of the Simulation Model

While the simulation model was developed primarily to test the output of the VMetric model for validation purposes, it has other uses that may benefit inventory managers at ARSC. The model can be used for what-if analyses to determine the effect of changes in input variables on outputs of interest. Several examples would include determining the effects of:

- Reducing re-supply or repair pipelines for specific parts
- Changing failure rates for specific parts
- Re-siting aircraft from one base to another
- Allowing Lateral Supply or not
- Changing shipping times on availability
- One particular part or a subset of parts on availability

- Differences in inputs on availability between bases
- Different stocking policies on shipping costs

The model can also be used to determine new measures of effectiveness for the system including:

- The percentage of time that a base will have a specified number of aircraft available
- Individual aircraft availability with confidence intervals
- Aircraft availability broken down by district, area, or other logical boundaries

ARSC has an ARENA software license and can run the simulation model to take advantage of the model for inventory planning purposes.

Appendix B SIMULATION MODEL INPUT DATA

This appendix provides the input data used to perform the validation runs for this study.

The stocking levels in Table B-1. were determined using AMMIS snapshots of inventory levels at the bases and the depot. Eight months of data were obtained and averaged. Some of the bases had large fluctuations in the number of parts during the 8 months and in those cases an estimated level was used. The AMMIS queries did not account for parts in repair or procurement pipelines so these stock levels are probably low end estimates. The total inventory valuation was $3,054,965.

Table B-1. Stocking Policy for Validation Run (Low End Estimate H2)

	Base									
Part	Cape Cod	Eliz City	Clear water	Mobile	San Diego	Astoria	Sitka	Kodiak	ARSC	Total
Dampener	1	0	1	0	1	0	1	0	2	6
TR Servo	1	0	1	1	1	0	1	1	4	10
Tip Cap	2	2	2	2	1	3	3	1	4	20
TDP	0	0	1	0	0	0	0	1	3	5
Pitch Trim	0	0	0	1	0	0	1	2	2	6
Main Rotor Blade	1	0	1	1	1	1	1	2	2	10
Elastomeric Bearing	1	1	1	1	1	1	1	1	8	16
Tail Rotor Blade	1	1	1	1	1	1	1	1	3	11

The allowance list stocking policy, Table B-2., is a high end estimate of how many parts were on hand during FY96 at the bases and ARSC. The number of parts on hand for the bases and ARSC were obtained from AMMIS which gave a total inventory valuation of $13,013,575.

Table B-2. Stocking Policy for Validation Run (High End Estimate H1)

	Base									
Part	Cape Cod	Eliz City	Clear water	Mobile	San Diego	Astoria	Sitka	Kodiak	ARSC	Total
Dampener	4	1	3	2	3	3	4	6	24	50
TR Servo	1	0	1	1	0	1	1	1	11	17
Tip Cap	4	4	12	4	2	4	2	6	43	81
TDP	0	0	0	0	0	0	0	0	21	21
Pitch Trim	2	0	2	2	2	2	2	2	8	22
Main Rotor Blade	3	0	18	3	3	3	3	3	23	59
Elastomeric Bearing	2	6	2	2	2	2	2	6	55	79
Tail Rotor Blade	2	0	2	1	2	1	1	1	30	40

The Failure rates were based on the following distributions which were determined using FY96 demand data and are shown in table B-3. See the section on the Poisson Demand Assumption for detail of how the distributions were fit.

Table B-3. Failure Distributions for Parts

Part	Distribution Used
Dampener	EXPONENTIAL(4.25)
TR Servo	EXPONENTIAL(17)
Tip Cap	-0.5 + LOGNORMAL(3.39, 4.56)
TDP	EXPONENTIAL(20.4)
Pitch Trim	EXPONENTIAL(31.8)
Main Rotor Blade	EXPONENTIAL(16.4)
Elastomeric Bearing	EXPONENTIAL(7.79)
Tail Rotor Blade	UNIFORM(1, 25.5)

The procurement and repair lead-time distributions were constructed from fiscal year 96 AMMIS data. All units are in days. Some parts are always be repaired or turned in for replacement and are indicated by the "no procurement" code in table B-4. A single number indicates that an average time or an estimate was used due to lack of sufficient data to fit a probability distribution.

Table B-4. Repair and Procurement Distributions (Time in Days)

Part	Repair Distribution	Procurement Distribution
Dampener	Lognormal(3.91,11.1)	no procurement*
TR Servo	8+371*Beta(.593,3.32)	56.7
Tip Cap	Lognormal(71.5,153)	Normal(11.9,3.2)
TDP	5.9	72.2
Pitch Trim	Normal(179,80)	30
Main Rotor Blade	4+315*Beta(.739,1.37)	111.29
Elastomeric Bearing	200*Beta(.214,1.24)	no procurement*
Tail Rotor Blade	Weibull (172,1.21)	no procurement*

* Part is always repaired or turned in for replacement

The average time to ship parts from bases to the depot was determined using data obtained from the chief of the Materials Section at ARSC for FEDEX shipments. Elizabeth City is a special case because it is co-located with ARSC. Shipping times were determined to be on average 1 day for air station Elizabeth City.

Table B-5. Base to Depot Shipping Times

Base	Days to Depot
Cape Cod	2
Ecity	1
Clearwater	2
Mobile	2
San Diego	2
Astoria	2
Sitka	4
Kodiak	3

The number of days between air stations for lateral supply was also obtained from the Materials Section at ARSC and are shown in Table B-6.

Table B-6. Shipping Times Between Bases

	Ecity	ClearWtr	Mobile	San Diego	Astoria	Sitka	Kodiak
CapeCod	2	3	2	3	4	7	7
	Ecity	2	2	3	4	7	7
		ClearWtr	2	3	4	7	7
			Mobile	3	4	7	7
				San Diego	3	4	4
					Astoria	4	4
						Sitka	2
							Kodiak

Average times to remove, repair and install parts were obtained by soliciting information from inventory managers at ARSC and air station engineering officers. A zero repair time in the base repair column of Table B-7. indicates that the part is never repaired at the base.

Table B-7. Base Repair Times and Remove & Install Times for Parts

	Base Repair Times (hours)	Base Remove and Install Times (hours)
Dampener	1.5	6.5
TR Servo	0	5.6
Tip Cap	0	2.0
TDP	0	2.0
Pitch Trim	0	5.0
Main Rotor Blade	4	2.0
Elastomeric Bearing	0	21.5
Tail Rotor Blade	3	12.5

The probability of a part being repaired at the base or the depot and their scrap rates are listed in Table B-8. The carcass scrap rate is equivalent to the percentage of the time the part is procured from a vendor instead of being repaired.

Table B-8. Base Repair, Depot Repair and Carcass Scrap Probabilities

	Base Repair Probability	Depot Repair Probability	Carcass Scrap Probability
Dampener	0.25	0.75	0
TR Servo	0	0.9	0.1
Tip Cap	0	0.9	0.1
TDP	0	0.99	0.01
Pitch Trim	0	0.9	0.1
Main Rotor Blade	0.1	0.8	0.1
Elastomeric Bearing	0	1	0
Tail Rotor Blade	0.1	0.9	0

Appendix C VMETRIC MODEL OUTPUT

The VMetric algorithm allocates parts one iteration at a time to maximize availability for least cost. The table below shows each buy decision made by VMetric as it attempts to achieve 100% availability. In this case, there was no funding constraint so VMetric kept adding stock until it reached 100% availability (Ao). The cumulative stock position at each iteration is a recommended stocking policy and corresponds to a point on the cost vs. Availability curve shown in figure 1. "Ech" indicates at which echelon the part should be located, the base (B) or depot (D). Total is the cumulative total for that part type in the recommended policy up to that iteration. Note that each stocking decision at the base echelon will increase total stock for that part by multiples of 8 parts because there are 8 bases and all must receive the same stock levels.

The stocking policy up to and including iteration 103 corresponds to the recommended stocking policy V2 from the section comparing the VMetric policy to the historical policy. The stocking policy up to and including iteration 133 corresponds to the recommended stocking policy V1.

Table C-1. VMetric Model Output With Unlimited Stock

Iteration	Cost (shadow price)	Ao	Site Fill Rt	Ech	Total	Part Name	Detla Ao/Delta Cost	Cost (shadow price)
2	5350	0.0798	0	D	1	TIP CAP ASSY	1.12E-06	5
3	10700	0.08577	0	D	2	TIP CAP ASSY	1.12E-06	11
4	16050	0.09174	0	D	3	TIP CAP ASSY	1.12E-06	16
5	21400	0.09771	0	D	4	TIP CAP ASSY	1.12E-06	21
6	26750	0.10368	0	D	5	TIP CAP ASSY	1.12E-06	27
7	32100	0.10965	0	D	6	TIP CAP ASSY	1.12E-06	32
8	37450	0.11561	0	D	7	TIP CAP ASSY	1.11E-06	37
9	42800	0.12157	0	D	8	TIP CAP ASSY	1.11E-06	43
10	48150	0.12751	0	D	9	TIP CAP ASSY	1.11E-06	48
11	53500	0.13341	0	D	10	TIP CAP ASSY	1.10E-06	54
12	58850	0.13924	0	D	11	TIP CAP ASSY	1.09E-06	59
13	64200	0.14495	0	D	12	TIP CAP ASSY	1.07E-06	64
14	69550	0.15048	0	D	13	TIP CAP ASSY	1.03E-06	70
15	74900	0.15575	0	D	14	TIP CAP ASSY	9.85E-07	75
16	80250	0.16068	0	D	15	TIP CAP ASSY	9.21E-07	80
17	85600	0.16518	0	D	16	TIP CAP ASSY	8.41E-07	86
18	90950	0.16919	0	D	17	TIP CAP ASSY	7.49E-07	91
19	96300	0.17266	0	D	18	TIP CAP ASSY	6.49E-07	96
20	101650	0.17558	0	D	19	TIP CAP ASSY	5.45E-07	102
21	109130	0.17918	0	D	1	DAMPENER,VIBR,DR SH	4.82E-07	109

Iteration	Cost (shadow price)	Ao	Site Fill Rt	Ech	Total	Part Name	Detla Ao/Delta Cost	Cost (shadow price)
22	122380	0.18572	0	D	1	BEARING,ELASTOMERIC	4.93E-07	122
23	127730	0.18823	0	D	20	TIP CAP ASSY	4.70E-07	128
24	140980	0.19452	0	D	2	BEARING,ELASTOMERIC	4.75E-07	141
25	154230	0.20006	0	D	3	BEARING,ELASTOMERIC	4.18E-07	154
26	159580	0.20216	0	D	21	TIP CAP ASSY	3.94E-07	160
27	172830	0.20661	0	D	4	BEARING,ELASTOMERIC	3.36E-07	173
28	178180	0.20825	0	D	22	TIP CAP ASSY	3.07E-07	178
29	202230	0.21891	0	D	1	BLADE ROTARY,RU	4.43E-07	202
30	226280	0.22957	0	D	2	BLADE ROTARY,RU	4.43E-07	226
31	250330	0.24023	0	D	3	BLADE ROTARY,RU	4.43E-07	250
32	274380	0.25087	0	D	4	BLADE ROTARY,RU	4.42E-07	274
33	298430	0.26146	0	D	5	BLADE ROTARY,RU	4.40E-07	298
34	322480	0.27194	0	D	6	BLADE ROTARY,RU	4.36E-07	322
35	346530	0.28217	0	D	7	BLADE ROTARY,RU	4.25E-07	347
36	370580	0.29198	0	D	8	BLADE ROTARY,RU	4.08E-07	371
37	394630	0.30115	0	D	9	BLADE ROTARY,RU	3.81E-07	395
38	407880	0.30576	0	D	5	BEARING,ELASTOMERIC	3.48E-07	408
39	436240	0.31632	0	D	1	SERVO,TAIL ROTOR	3.73E-07	436
40	443720	0.31894	0	D	2	DAMPENER,VIBR,DR SH	3.49E-07	444
41	449070	0.3208	0	D	23	TIP CAP ASSY	3.48E-07	449
42	479880	0.33694	0	D	1	PITCH TRIM ASSY	5.24E-07	480
43	510690	0.35309	0	D	2	PITCH TRIM ASSY	5.24E-07	511
44	541500	0.36922	0	D	3	PITCH TRIM ASSY	5.24E-07	542
45	572310	0.38533	0	D	4	PITCH TRIM ASSY	5.23E-07	572
46	596360	0.39594	0	D	10	BLADE ROTARY,RU	4.41E-07	596
47	627170	0.41239	0	D	5	PITCH TRIM ASSY	5.34E-07	627
48	657980	0.42863	0	D	6	PITCH TRIM ASSY	5.27E-07	658
49	686340	0.44154	0	D	2	SERVO,TAIL ROTOR	4.55E-07	686
50	717150	0.45781	0	D	7	PITCH TRIM ASSY	5.28E-07	717
51	759950	0.47696	0.054	S	31	TIP CAP ASSY	4.47E-07	760
52	790760	0.49311	0.056	D	8	PITCH TRIM ASSY	5.24E-07	791
53	814810	0.50461	0.058	D	11	BLADE ROTARY,RU	4.78E-07	815
54	845620	0.5199	0.06	D	9	PITCH TRIM ASSY	4.96E-07	846
55	873980	0.53211	0.062	D	3	SERVO,TAIL ROTOR	4.31E-07	874
56	904790	0.5461	0.065	D	10	PITCH TRIM ASSY	4.54E-07	905
57	928840	0.5565	0.067	D	12	BLADE ROTARY,RU	4.32E-07	929

Iteration	Cost (shadow price)	Ao	Site Fill Rt	Ech	Total	Part Name	Detla Ao/Delta Cost	Cost (shadow price)
58	942090	0.56182	0.068	D	6	BEARING,ELASTOMERIC	4.02E-07	942
59	972900	0.57417	0.07	D	11	PITCH TRIM ASSY	4.01E-07	973
60	1020760	0.59887	0.075	D	1	BLADE,ROTARY WING	5.16E-07	1021
61	1068620	0.62352	0.08	D	2	BLADE,ROTARY WING	5.15E-07	1069
62	1116480	0.64799	0.085	D	3	BLADE,ROTARY WING	5.11E-07	1116
63	1164340	0.67195	0.091	D	4	BLADE,ROTARY WING	5.01E-07	1164
64	1212200	0.69483	0.098	D	5	BLADE,ROTARY WING	4.78E-07	1212
65	1236250	0.70519	0.102	D	13	BLADE ROTARY,RU	4.31E-07	1236
66	1284110	0.72653	0.109	D	6	BLADE,ROTARY WING	4.46E-07	1284
67	1312470	0.73822	0.114	D	4	SERVO,TAIL ROTOR	4.12E-07	1312
68	1343280	0.75126	0.12	D	12	PITCH TRIM ASSY	4.23E-07	1343
69	1391140	0.77058	0.13	D	7	BLADE,ROTARY WING	4.04E-07	1391
70	1415190	0.7792	0.135	D	14	BLADE ROTARY,RU	3.59E-07	1415
71	1446000	0.7898	0.141	D	13	PITCH TRIM ASSY	3.44E-07	1446
72	1493860	0.80617	0.152	D	8	BLADE,ROTARY WING	3.42E-07	1494
73	1507110	0.81051	0.155	D	7	BEARING,ELASTOMERIC	3.28E-07	1507
74	1566950	0.82799	0.237	S	10	DAMPENER,VIBR,DR SH	2.92E-07	1567
75	1595310	0.836	0.246	D	5	SERVO,TAIL ROTOR	2.83E-07	1595
76	1619360	0.84273	0.255	D	15	BLADE ROTARY,RU	2.80E-07	1619
77	1650170	0.85118	0.266	D	14	PITCH TRIM ASSY	2.74E-07	1650
78	1698030	0.86461	0.286	D	9	BLADE,ROTARY WING	2.81E-07	1698
79	1703380	0.86568	0.277	D	32	TIP CAP ASSY	1.99E-07	1703
80	1751240	0.87547	0.293	D	10	BLADE,ROTARY WING	2.05E-07	1751
81	1775290	0.88032	0.301	D	16	BLADE ROTARY,RU	2.01E-07	1775
82	1806100	0.88654	0.313	D	15	PITCH TRIM ASSY	2.02E-07	1806
83	1819350	0.88897	0.318	D	8	BEARING,ELASTOMERIC	1.84E-07	1819
84	1847710	0.89355	0.327	D	6	SERVO,TAIL ROTOR	1.61E-07	1848
85	1895570	0.90037	0.342	D	11	BLADE,ROTARY WING	1.43E-07	1896
86	1900920	0.90112	0.336	D	33	TIP CAP ASSY	1.40E-07	1901
87	1931730	0.90542	0.346	D	16	PITCH TRIM ASSY	1.39E-07	1932
88	1955780	0.90872	0.354	D	17	BLADE ROTARY,RU	1.37E-07	1956
89	2061780	0.92176	0.446	S	16	BEARING,ELASTOMERIC	1.23E-07	2062
90	2067130	0.92227	0.442	D	34	TIP CAP ASSY	9.38E-08	2067
91	2114990	0.92674	0.456	D	12	BLADE,ROTARY WING	9.36E-08	2115
92	2145800	0.92959	0.466	D	17	PITCH TRIM ASSY	9.23E-08	2146

Iteration	Cost (shadow price)	Ao	Site Fill Rt	Ech	Total	Part Name	Detla Ao/Delta Cost	Cost (shadow price)
93	2169850	0.93172	0.474	D	18	BLADE ROTARY,RU	8.87E-08	2170
94	2198210	0.93399	0.482	D	7	SERVO,TAIL ROTOR	8.00E-08	2198
95	2241010	0.93666	0.516	S	42	TIP CAP ASSY	6.24E-08	2241
96	2271820	0.93843	0.523	D	18	PITCH TRIM ASSY	5.74E-08	2272
97	2319680	0.94116	0.534	D	13	BLADE,ROTARY WING	5.70E-08	2320
98	2343730	0.94246	0.54	D	19	BLADE ROTARY,RU	5.42E-08	2344
99	2536130	0.95049	0.605	S	27	BLADE ROTARY,RU	4.17E-08	2536
100	2832025	0.96298	0.67	D	1	Computer, Navigation	4.22E-08	2832
101	2860385	0.96397	0.676	D	8	SERVO,TAIL ROTOR	3.51E-08	2860
102	2891195	0.96504	0.683	D	19	PITCH TRIM ASSY	3.48E-08	2891
103	2939055	0.96663	0.692	D	14	BLADE,ROTARY WING	3.31E-08	2939
104	3185535	0.97415	0.76	S	27	PITCH TRIM ASSY	3.05E-08	3186
105	3193015	0.97433	0.759	D	11	DAMPENER,VIBR,DR SH	2.49E-08	3193
106	3419895	0.97986	0.809	S	16	SERVO,TAIL ROTOR	2.44E-08	3420
107	3802775	0.98859	0.888	S	22	BLADE,ROTARY WING	2.28E-08	3803
108	3816025	0.9888	0.887	D	17	BEARING,ELASTOMERIC	1.60E-08	3816
109	3875865	0.98952	0.9	S	19	DAMPENER,VIBR,DR SH	1.21E-08	3876
110	4171760	0.99262	0.926	D	2	Computer, Navigation	1.05E-08	4172
111	4177110	0.99267	0.926	D	43	TIP CAP ASSY	8.19E-09	4177
112	4182460	0.99271	0.926	D	44	TIP CAP ASSY	8.51E-09	4182
113	4206510	0.99284	0.926	D	28	BLADE ROTARY,RU	5.21E-09	4207
114	4312510	0.99318	0.932	S	25	BEARING,ELASTOMERIC	3.28E-09	4313
115	4343320	0.99328	0.932	D	28	PITCH TRIM ASSY	3.07E-09	4343
116	4367370	0.99335	0.932	D	29	BLADE ROTARY,RU	2.77E-09	4367
117	4415230	0.99346	0.932	D	23	BLADE,ROTARY WING	2.49E-09	4415
118	4458030	0.99357	0.935	S	52	TIP CAP ASSY	2.40E-09	4458
119	4482080	0.99362	0.935	D	30	BLADE ROTARY,RU	2.40E-09	4482
120	6849240	0.9993	0.99	S	10	Computer, Navigation	2.40E-09	6849
121	6897100	0.99939	0.99	D	24	BLADE,ROTARY WING	1.89E-09	6897
122	6927910	0.99944	0.99	D	29	PITCH TRIM ASSY	1.60E-09	6928
123	6956270	0.99949	0.99	D	17	SERVO,TAIL ROTOR	1.50E-09	6956
124	6987080	0.99953	0.99	D	30	PITCH TRIM ASSY	1.32E-09	6987
125	7179480	0.99963	0.992	S	38	BLADE ROTARY,RU	5.49E-10	7179
126	7425960	0.99972	0.994	S	38	PITCH TRIM ASSY	3.75E-10	7426

Iteration	Cost (shadow price)	Ao	Site Fill Rt	Ech	Total	Part Name	Detla Ao/Delta Cost	Cost (shadow price)
127	7485800	0.99974	0.995	S	27	DAMPENER,VIBR,DR SH	3.18E-10	7486
128	7868680	0.99986	0.997	S	32	BLADE,ROTARY WING	3.15E-10	7869
129	8095560	0.99992	0.998	S	25	SERVO,TAIL ROTOR	2.49E-10	8096
130	8138360	0.99992	0.998	S	60	TIP CAP ASSY	8.43E-11	8138
131	8244360	0.99993	0.999	S	33	BEARING,ELASTOMERIC	5.90E-11	8244
132	8540255	0.99994	0.999	D	11	Computer, Navigation	3.84E-11	8540
133	10907415	1	1	S	19	Computer, Navigation	2.28E-11	10907

Appendix D AIR STATION FIELD TEST DATA

The following table lists the demand and re-supply events recorded at Air Stations Cape Cod and Astoria from 1 March through mid-June. Only data on the subset of 8 parts are included in this table. A listing of all demands was collected but is not included in this report.

Table D-1. Failure and Re-supply Data for Subset of Parts

Cape Cod	1March - 5Jun								
Part	Base Demand and Re-supply Time/Date	QOH	Quantity demanded	Demand filled	Method	Helo down	Parts Pool From	Parts Pool To	Qty BO
Tip Cap	10-Mar	1	1	10-Mar	E*				
Tip Cap	14-Mar	0	1	17-Mar	B				
Pitch trim	17-Mar	0	1	4-Apr	B				
damper	27-Mar	0	1	4-Apr	B				
damper	27-Mar	0	1	4-Apr	B				
damper		4	1	22-Apr	R				
Tip Cap	29-Apr	1	1		C	6008		san diego	1
Main Rotor Blade		2	1	29-Apr	R				
Main Rotor Blade		3	1	29-Apr	R				
damper	5-May	3	1	5-May	E				
damper		3	1	20-May	R				1
damper		4	1	27-May	R				0
Elastomeric Bearing	5-Jun	2	2	13-Jun	E	6007			2
Tip Cap	3-Jun	0	2	6-Jun	B	6007			2
Elastomeric Bearing	5-Jun	0	1	13-Jun	B	6007			3

Astoria	1March - 04 June								
Part	Base Demand and Re-supply Time/Date	QOH	Quantity demanded	Demand filled	Method	Helo down	Parts Pool From	Parts Pool To	Qty BO
tip cap	30-Mar	?	?	?	?	?	?	?	?
tip cap	30-Apr	2	1	30-Apr	E	6013			
tip cap	30-Apr	1	1	30-Apr	E	6036			
TR servo	6-May	1	1	20-May	E	6013			
tail rotor blade	7-May	0	1	17-May	C	6013	mobile		
pitch trim	7-May	0	1	15-May	B	6013			1
TR servo	27-May	0	1	30-May	B	6003			1

- B - Part not on hand at base, requested from ARSC
- C - Part not on hand at base, parts pooled from other air station or Part on hand at base, part pooled TO other air station
- E - Part on hand at base, taken from shelf
- R - Re-supply of part

The following table computes the total aircraft down time for Air Stations Cape Cod and Astoria during the field test period. The first section for each base is based on the actual stock levels that were on hand at the time of the tests. The following two sections indicate how down time would have been affected had the VMetric stocking recommendation been used.

Table D-2. Computation of Total Hours Down

Cape Cod Field Test Results

Data Collected 1 March- 5 June

Part	Date Part Failed	Quantity Demanded	Days Backordered	Remove/Install Time (hrs)	Hours Down
Tip Cap	10-Mar	1	0	2	2.0
Tip Cap	14-Mar	1	3	2	74.0
damper	5-May	1	0	6.5	6.5
Elastomeric Bearing	5-Jun	2	0	21.5	21.5
Tip Cap	3-Jun	2	3	2	74.0
Elastomeric Bearing	5-Jun	1	8	21.5	213.5
Total number of BO's	4			Total Hours Down	391.5

VMetric policy results ($2.9M)

Part	Date Part Failed	Quantity Demanded	Days Backordered	Remove/Install Time (hrs)	Hours Down
Tip Cap	10-Mar	1	0	2	2.0
Tip Cap	14-Mar	1	0	2	2.0
damper	5-May	1	0	6.5	6.5
Elastomeric Bearing	5-Jun	2	1	21.5	45.5
Tip Cap	3-Jun	2	0	2	2.0
Elastomeric Bearing	5-Jun	1	8	21.5	213.5
Total number of BO's	2			Total Hours Down	271.5

VMETRIC policy results ($10.9M)

Part	Date Part Failed	Quantity Demanded	Days Backordered	Remove/Install Time (hrs)	Hours Down
Tip Cap	10-Mar	1	0	2	2.0
Tip Cap	14-Mar	1	0	2	2.0
damper	5-May	1	0	6.5	6.5
Elastomeric Bearing	5-Jun	2	0	21.5	21.5
Tip Cap	3-Jun	2	0	2	2.0
Elastomeric Bearing	5-Jun	1	0	21.5	21.5
Total number of BO's	3			Total Hours Down	55.5

ASTORIA Field Test Results

Data Collected 1 March - 4 June

Part	Date Part Failed	Quantity Demanded	Days Backordered	Remove/Install Time (hrs)	Hours Down
tip cap	30-Apr	1	0	4	4.0
tip cap	30-Apr	1	0	4	4.0
TR servo	6-May	1	0	5.6	5.6
tail rotor blade	7-May	1	10	12.5	252.5
pitch trim	7-May	1	8	5	197.0
TR servo	27-May	1	3	5.6	77.6
Total Number of BO's	3			Total Hours Down	540.7

VMETRIC policy results ($2.9M)

Part	Date Part Failed	Quantity Demanded	Days Backordered	Remove/Install Time (hrs)	Hours Down
tip cap	30-Apr	1	0	4	4.0
tip cap	30-Apr	1	0	4	4.0
TR servo	6-May	1	10	5.6	245.6
tail rotor blade	7-May	1	0	12.5	12.5
pitch trim	7-May	1	8	5	197.0
TR servo	27-May	1	3	5.6	77.6
Total Number of BO's	3			Total Hours Down	540.7

VMETRIC policy results ($10.9M)

Part	Date Part Failed	Quantity Demanded	Days Backordered	Remove/Install Time (hrs)	Hours Down
tip cap	30-Apr	1	0	4	4.0
tip cap	30-Apr	1	0	4	4.0
TR servo	6-May	1	0	5.6	5.6
tail rotor blade	7-May	1	0	12.5	12.5
pitch trim	7-May	1	0	5	5.0
TR servo	27-May	1	0	5.6	5.6
Total Number of BO's	0			Total Hours Down	36.7

Appendix E SIMULATION MODEL OUTPUT

The following table is a sample of the simulation model output for aircraft availability. It provides an average availability for each individual aircraft modeled in the simulation. An average availability for all the aircraft is derived from this data and used to compare the performance of different stocking policies.

Table E-1. Simulation Model Output (Availability For Each Aircraft)

Classical C.I. Intervals Summary

Low End Historical Stock With Lateral Supply

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Helo 1 Availability	0.909	0.0868	0.0247	0.591	0.99	50
Helo 2 Availability	0.916	0.0802	0.0228	0.641	0.993	50
Helo 3 Availability	0.92	0.0814	0.0231	0.672	0.988	50
Helo 4 Availability	0.925	0.0733	0.0208	0.645	0.985	50
Helo 5 Availability	0.89	0.124	0.0353	0.335	0.975	50
Helo 6 Availability	0.916	0.081	0.023	0.586	0.987	50
Helo 7 Availability	0.912	0.0802	0.0228	0.575	0.987	50
Helo 8 Availability	0.947	0.0354	0.01	0.844	0.996	50
Helo 9 Availability	0.923	0.0711	0.0202	0.692	0.985	50
Helo 10 Availability	0.92	0.0684	0.0194	0.71	0.995	50
Helo 11 Availability	0.927	0.0762	0.0217	0.635	0.989	50
Helo 12 Availability	0.918	0.0681	0.0194	0.692	0.985	50
Helo 13 Availability	0.921	0.0695	0.0197	0.636	0.997	50
Helo 14 Availability	0.923	0.0621	0.0177	0.735	0.996	50
Helo 15 Availability	0.911	0.0873	0.0248	0.54	0.99	50
Helo 16 Availability	0.905	0.0991	0.0282	0.419	0.983	50
Helo 17 Availability	0.91	0.0831	0.0236	0.639	0.976	50
Helo 18 Availability	0.913	0.0944	0.0268	0.594	0.993	50
Helo 19 Availability	0.921	0.0647	0.0184	0.686	0.986	50
Helo 20 Availability	0.892	0.12	0.034	0.279	0.992	50
Helo 21 Availability	0.915	0.0765	0.0218	0.582	0.989	50
Helo 22 Availability	0.889	0.11	0.0313	0.384	0.978	50
Helo 23 Availability	0.891	0.0925	0.0263	0.623	0.981	50
Helo 24 Availability	0.903	0.123	0.0349	0.441	0.989	50
Helo 25 Availability	0.926	0.0657	0.0187	0.727	0.994	50
Helo 26 Availability	0.94	0.0481	0.0137	0.783	0.992	50
Helo 27 Availability	0.903	0.124	0.0353	0.355	0.99	50
Helo 28 Availability	0.886	0.116	0.0329	0.524	0.978	50
Helo 29 Availability	0.908	0.0871	0.0248	0.63	0.995	50
Helo 30 Availability	0.909	0.0729	0.0207	0.691	0.991	50
Helo 31 Availability	0.888	0.126	0.0359	0.467	0.983	50

Appendix F PART FAILURE RATE STATISTICS

This appendix provides the data analysis output for the failure rates for the subset of parts used in this study. All data analysis was done using the input processor of the ARENA™ software package. The fit all summary lists the squared error of each of the probability distributions fit to the data in order of increasing error. The distribution summary lists the distribution used in the simulation model and it's parameters. Chi Square or Kolmogorov-Smirnov goodness of fit test results are also listed provided sufficient data were available to perform the tests. The data summary provides descriptive statistics for the input data used. Finally, a histogram of the data is displayed along with the fitted curve for the chosen distribution.[3]

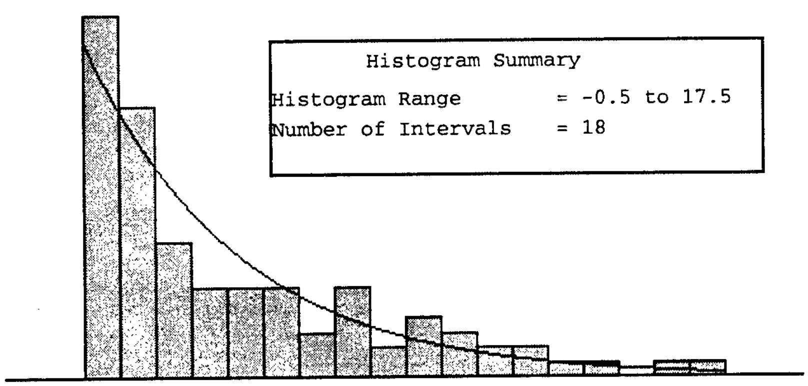
A. Dampener

Fit All Summary

Function	Sq Error
Beta	0.00728
Erlang	0.00736
Exponential	0.00736
Weibull	0.00762
Lognormal	0.0078
Gamma	0.00888
Triangular	0.0428
Normal	0.0555
Uniform	0.0746
Poisson	0.119

Data Summary

Number of Data Points	= 95
Min Data Value	= 0
Max Data Value	= 17
Sample Mean	= 3.75
Sample Std Dev	= 4.14



[3] Details about each test can be found in the ARENA User's Guide, Chapter 7 Fitting Data, pg. 119.

B. Elastomeric Bearing

Fit All Summary

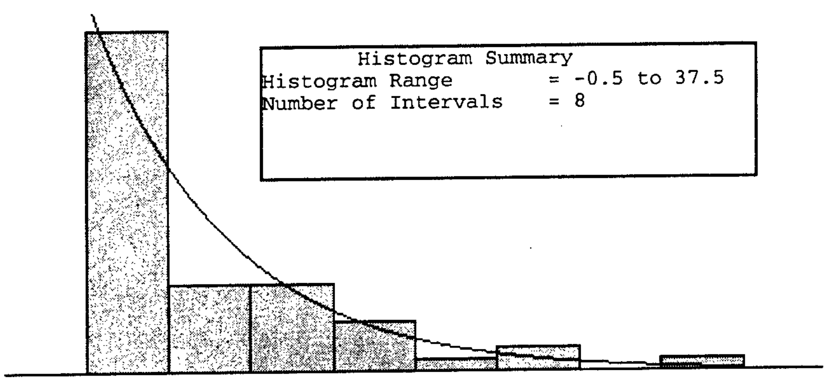
Function	Sq Error
Beta	0.0064
Lognormal	0.00985
Weibull	0.0178
Erlang	0.0187
Exponential	0.0187
Gamma	0.0221
Normal	0.143
Triangular	0.155
Uniform	0.22
Poisson	0.544

Distribution Summary

Distribution: Exponential
Expression: -0.5 + EXPO(7.79)
Square Error: 0.018691
Chi Square Test
  Number of intervals = 4
  Degrees of freedom = 2
  Test Statistic = 3.12
  Corresponding p-value = 0.221

Data Summary

Number of Data Points = 49
Min Data Value = 0
Max Data Value = 37
Sample Mean = 7.29
Sample Std Dev = 8.2



C. Hoist

Fit All Summary

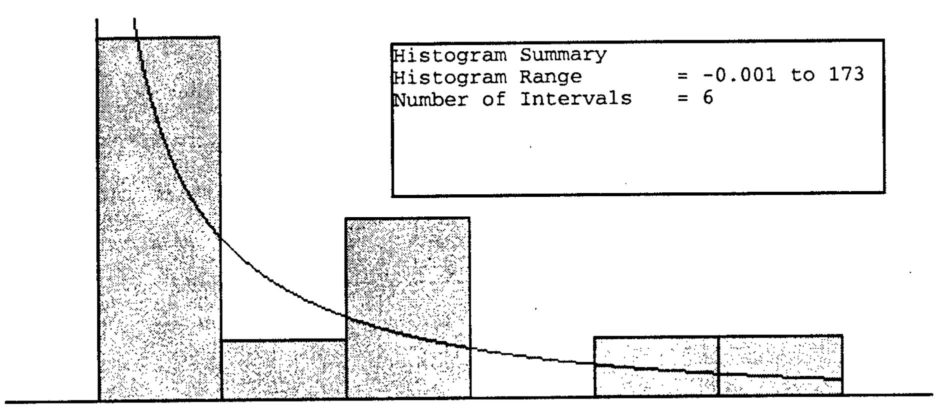
Function	Sq Error
Weibull	0.041
Gamma	0.0412
Lognormal	0.0559
Erlang	0.056
Exponential	0.056
Beta	0.0653
Triangular	0.129
Normal	0.157
Uniform	0.167

Distribution Summary

Distribution: Weibull
Expression: -0.001 + WEIB(44.4, 0.627)
Square Error: 0.041046
Kolmogorov-Smirnov Test
  Test Statistic = 0.243
  Corresponding p-value > 0.15

Data Summary

Number of Data Points	= 12
Min Data Value	= 0
Max Data Value	= 173
Sample Mean	= 54.8
Sample Std Dev	= 54.9



D. Main Rotor Blade

Fit All Summary

Function	Sq Error
Weibull	0.00263
Exponential	0.00699
Erlang	0.00699
Gamma	0.068
Beta	0.13
Lognormal	0.164
Normal	0.234
Triangular	0.41
Uniform	0.523

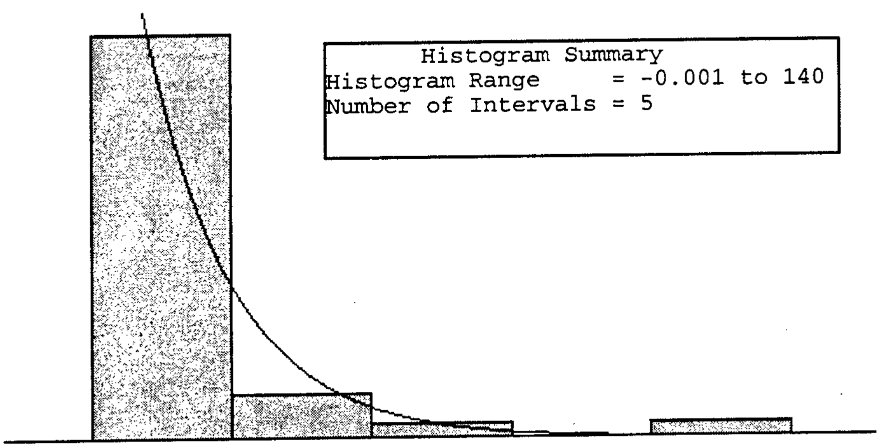
Distribution Summary

Distribution: Exponential
Expression: -0.001 + EXPO(17.3)
Square Error: 0.006986
Chi Square Test
  Number of intervals = 2
  Degrees of freedom = 0
  Test Statistic = 1.21
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic = 0.17
  Corresponding p-value > 0.15

Data Summary

Number of Data Points = 32
Min Data Value = 0
Max Data Value = 140
Sample Mean = 17.3
Sample Std Dev = 27.2



E. Pitch Trim Assembly

Fit All Summary

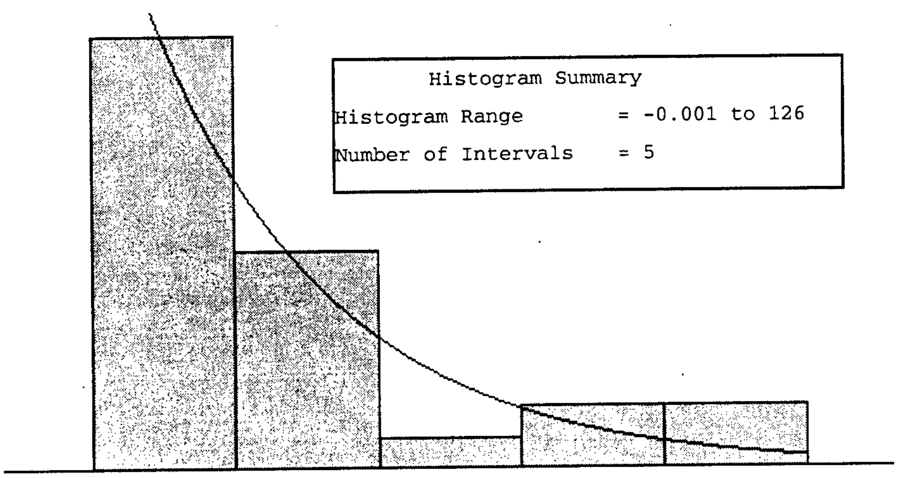
Function	Sq Error
Erlang	0.00956
Exponential	0.00956
Gamma	0.0163
Weibull	0.025
Lognormal	0.0431
Triangular	0.102
Beta	0.103
Normal	0.113
Uniform	0.176

Distribution Summary

Distribution: Exponential
Expression: -0.001 + EXPO(31.8)
Square Error: 0.009563
Chi Square Test
  Number of intervals = 2
  Degrees of freedom = 0
  Test Statistic = 0.0981
  Corresponding p-value < 0.005
Kolmogorov-Smirnov Test
  Test Statistic = 0.108
  Corresponding p-value > 0.15

Data Summary

Number of Data Points = 26
Min Data Value = 0
Max Data Value = 126
Sample Mean = 31.8
Sample Std Dev = 35.4



F. Roll Trim Assembly

Fit All Summary

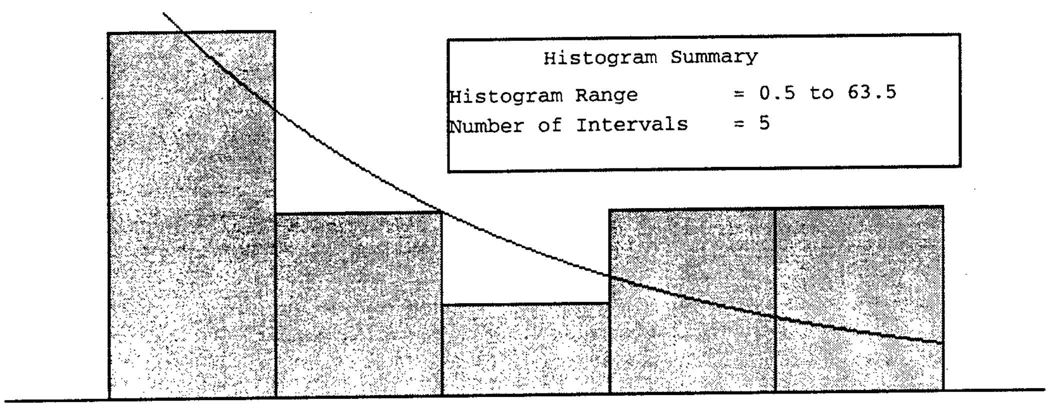
Function	Sq Error
Gamma	0.0301
Erlang	0.0307
Exponential	0.0307
Weibull	0.0341
Lognormal	0.0374
Uniform	0.0393
Triangular	0.065
Normal	0.0778
Beta	0.382
Poisson	0.443

Distribution Summary

Distribution: Exponential
Expression: 0.5 + EXPO(28.3)
Square Error: 0.030687

Data Summary

Number of Data Points	= 11
Min Data Value	= 1
Max Data Value	= 63
Sample Mean	= 28.8
Sample Std Dev	= 22.6



G. Tactical Data Processor

Fit All Summary

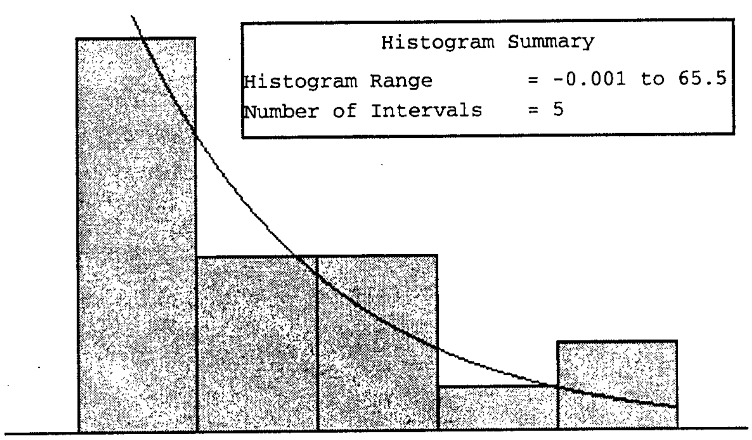
Function	Sq Error
Erlang	0.0119
Exponential	0.0119
Gamma	0.0194
Weibull	0.0373
Lognormal	0.0446
Triangular	0.0491
Normal	0.0723
Uniform	0.0966
Beta	0.104
Poisson	0.66

Distribution Summary

Distribution: Exponential
Expression: -0.001 + EXPO(20.4)
Square Error: 0.011856
Chi Square Test
  Number of intervals = 2
  Degrees of freedom = 0
  Test Statistic = 0.198
  Corresponding p-value < 0.005

Data Summary

Number of Data Points	= 20
Min Data Value	= 0
Max Data Value	= 65
Sample Mean	= 20.4
Sample Std Dev	= 20.4



H. Tip Cap

Fit All Summary

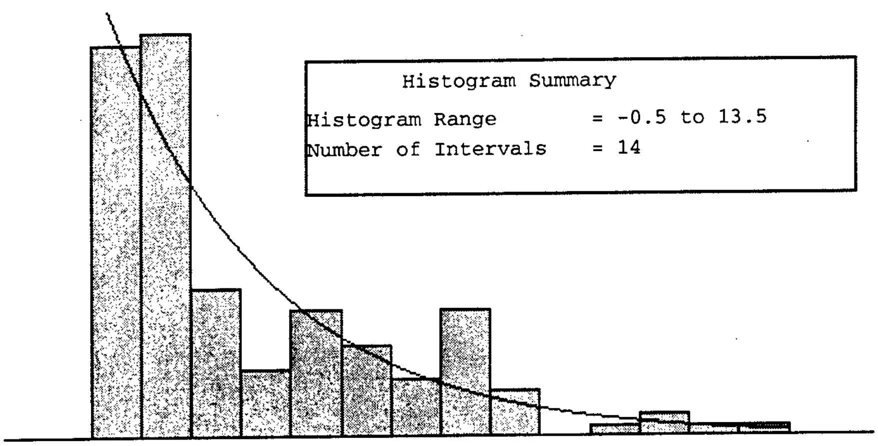
Function	Sq Error
Lognormal	0.011
Exponential	0.0138
Erlang	0.0138
Weibull	0.0159
Gamma	0.0165
Beta	0.0187
Normal	0.0664
Triangular	0.0785
Uniform	0.0973
Poisson	0.107

Distribution Summary

Distribution: Exponential
Expression: -0.5 + EXPO(3.22)
Square Error: 0.013773
Chi Square Test
  Number of intervals = 7
  Degrees of freedom = 5
  Test Statistic = 15.7
  Corresponding p-value = 0.00808

Data Summary

Number of Data Points = 132
Min Data Value = 0
Max Data Value = 13
Sample Mean = 2.72
Sample Std Dev = 2.99



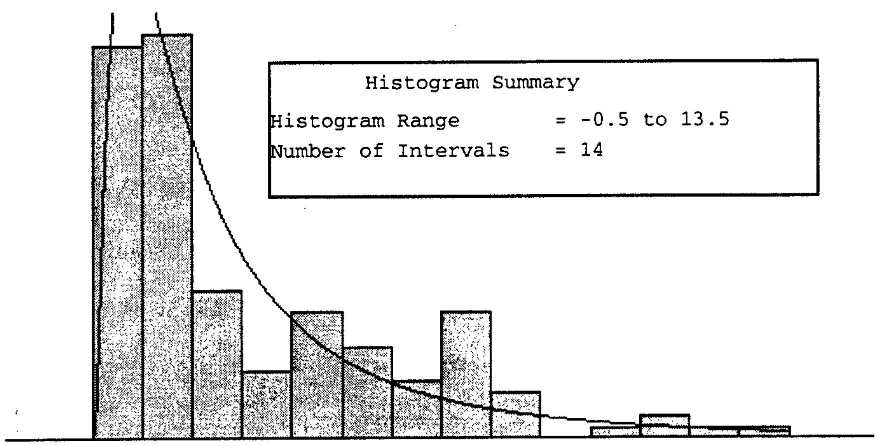
Tip Cap with lognormal also

Distribution Summary

```
Distribution: Lognormal
Expression:   -0.5 + LOGN(3.39, 4.56)
Square Error: 0.011034
Chi Square Test
  Number of intervals      = 6
  Degrees of freedom       = 3
  Test Statistic           = 21.9
  Corresponding p-value    < 0.005
```

Data Summary

```
Number of Data Points      = 132
Min Data Value             = 0
Max Data Value             = 13
Sample Mean                = 2.72
Sample Std Dev             = 2.99
```



I. Tail Rotor Blade

Fit All Summary

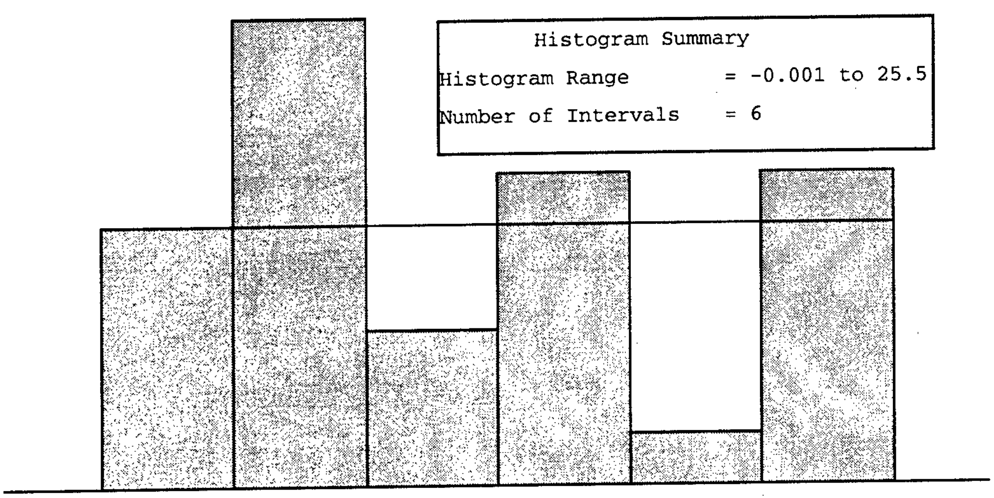
Function	Sq Error
Uniform	0.0412
Triangular	0.0538
Normal	0.0574
Poisson	0.26
Weibull	0.694
Lognormal	-1.#J
Erlang	0.0623
Exponential	0.0623
Gamma	0.136
Beta	1.51

Distribution Summary

Distribution: Uniform
Expression: UNIF(-0.001, 25.5)
Square Error: 0.041185
Chi Square Test
  Number of intervals = 3
  Degrees of freedom = 2
  Test Statistic = 3.82
  Corresponding p-value = 0.165

Data Summary

Number of Data Points = 30
Min Data Value = 0
Max Data Value = 25
Sample Mean = 10.5
Sample Std Dev = 7.61



J. Tail Rotor Servo

Fit All Summary

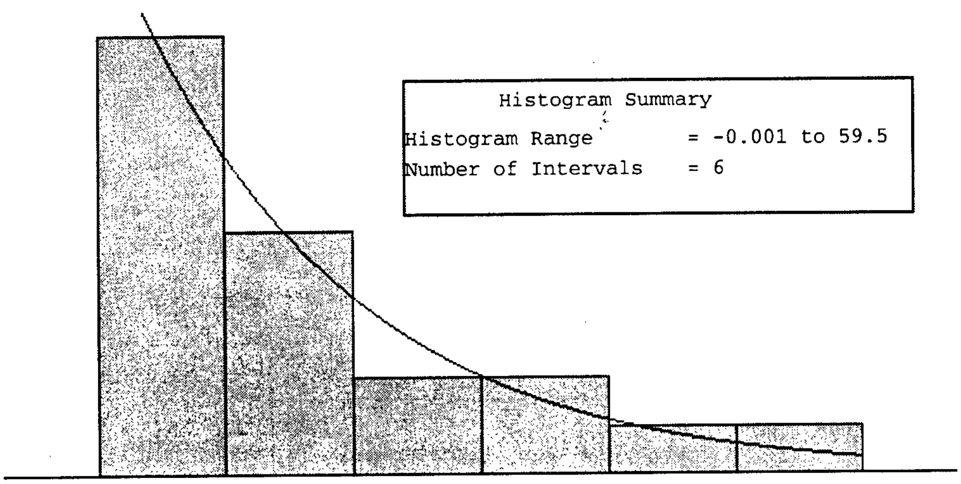
Function	Sq Error
Erlang	0.00279
Exponential	0.00279
Weibull	0.00341
Gamma	0.00345
Beta	0.0106
Lognormal	0.0253
Triangular	0.0603
Normal	0.0849
Uniform	0.121
Poisson	0.689

Distribution Summary

Distribution: Exponential
Expression: -0.001 + EXPO(17)
Square Error: 0.002794
Chi Square Test
  Number of intervals = 2
  Degrees of freedom = 0
  Test Statistic = 0.0859
  Corresponding p-value < 0.005

Data Summary

Number of Data Points = 20
Min Data Value = 0
Max Data Value = 59
Sample Mean = 16.9
Sample Std Dev = 16.1



Histogram Summary

Histogram Range = -0.001 to 59.5
Number of Intervals = 6